Appendix L

Technology Transfer Package

A Preliminary Mechanistic Evaluation of PCC Cross-Sections Using ISLAB2000 – A Parametric Study

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Part I: ISLAB2000 Tutorial

Pavement Structure

The first step of modeling using ISLAB2000 is to identify the structural features and material properties of the pavement system. To do so, perform the following procedure.

Step 1: Define Pavement Dimensions, Coordinate System, and FE Mesh Options

To input pavement dimensions, select **Geometry** from the main panel. The geometry panel appears (see Figure 1). In the **X-direction** section, click **Insert** to add shoulder and lane dimensions for the pavement system. In the **Y-direction** section, click **Insert** to add slab dimensions for the pavement system. Note that ISLAB2000 uses a rectangular coordinate system with X-direction in the transverse direction and Y-direction in the longitudinal direction, and the origin is at the left corner of the pavement system.

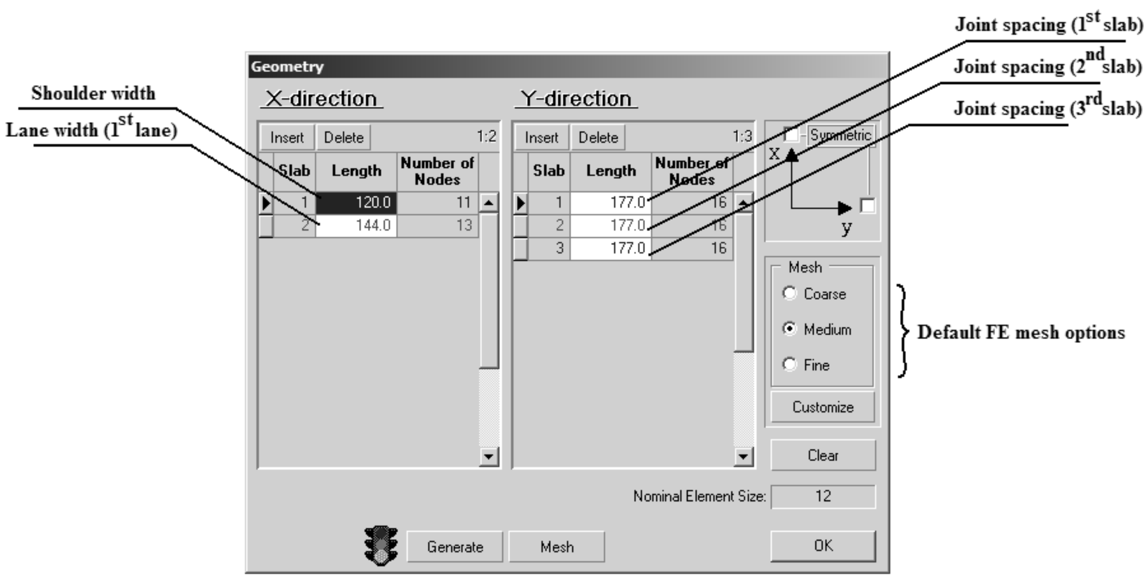


Figure 1: Geometry Panel

Three default finite element (FE) mesh options are available: coarse (24 in.), medium (12 in.), and fine (6 in.). To define FE mesh other than the defaults, click **Customize**, and then enter a new nominal element size.

After selecting mesh size, click **Generate** and then click **OK** to close the geometry panel and return to the main panel. Based on the inputs, the main panel displays the plan view of the pavement system as illustrated in Figure 2.

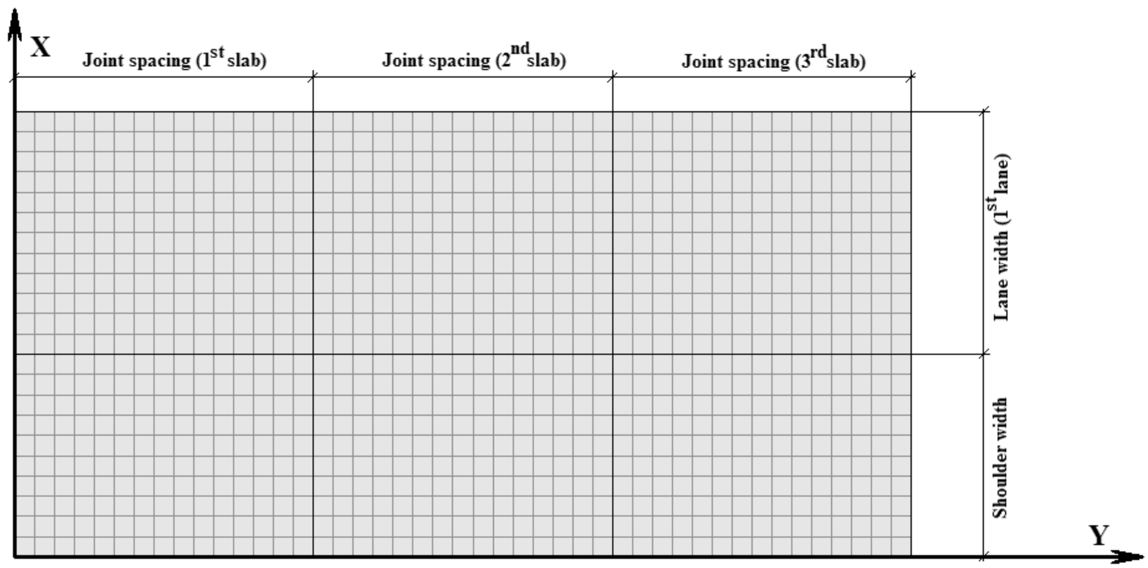


Figure 2: Plan View of the Pavement System

Step 2: Define Layer Thickness and Typical Parameters for Material Properties

To define the thickness of layers and the design parameters, select **Layers** from the main panel. The layers panel appears (see Figure 3). Click **Add Layer** to enter the number of layers required for the design.

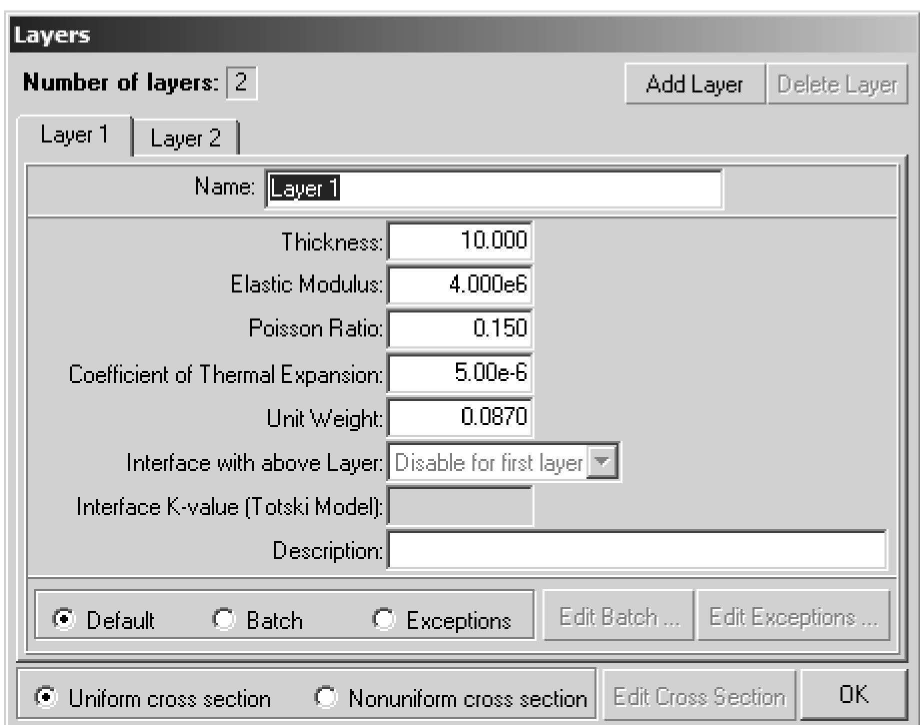


Figure 3: Layers Panel

After you enter the necessary layers you can enter the design parameters for each layer, including thickness (in.), elastic modulus (psi), Poisson's ratio, CTE (in./in./^{o}F), unit weight (lb/in.^{3}), and interface condition between two layers (only layers beneath PCC layer). Table 1 lists typical design parameter values.

Layers	Design parameters				
	Elastic modulus (psi)	Poisson's ratio	CTE (in./in./^{o}F)	Unit weight (lb/in.^{3})	Interface condition
PCC slab	4,000,000	0.15	$5x10^{-6}$	0.087	-
Aggregate base	30,000	0.35	$2x10^{-6}$	0.061	Unbonded
Asphalt treated base	300,000	0.35	$2x10^{-6}$	0.061	Bonded/unbonded
Lean concrete base	2,000,000	0.20	$4x10^{-6}$	0.087	Bonded/unbonded
Sand subbase	15,000	0.35	$2x10^{-6}$	0.061	Unbonded

Table 1: Typical values of design parameters for layers module
(Sources: Huang (1993), Klieger and Lamond (1994))

Step 3: Define Subgrade Model and Typical Parameters for Roadbed Soil

To define the design parameter for subgrade model, select **Subgrade** from the main panel. The subgrade panel appears (see Figure 4).

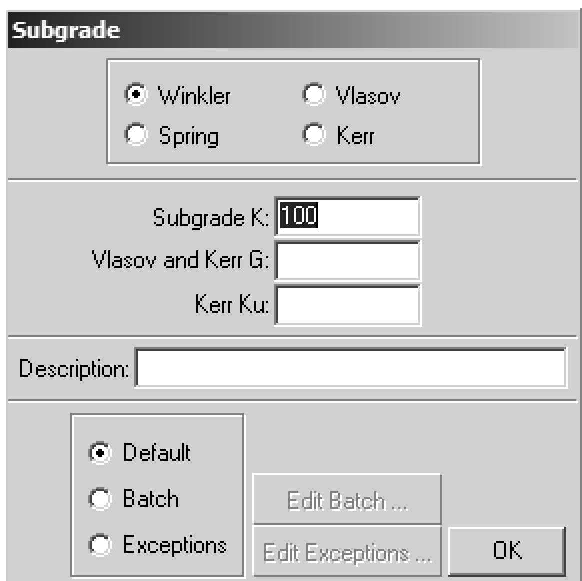


Figure 4: Subgrade Panel

Four subgrade models are available in ISLAB2000. In general, Winkler foundation is used in the design. Input for this subgrade model is **Subgrade K** (modulus of subgrade reaction, psi/in.).

Step 4: Define Transverse and Longitudinal Joints and Typical Inputs for Joint Designs

To define design parameters for joint design, select **Joints** from the main panel. The joints panel appears (see Figure 5). **Joints in x-direction** and **Joints in y-direction** are longitudinal and transverse joints, respectively.

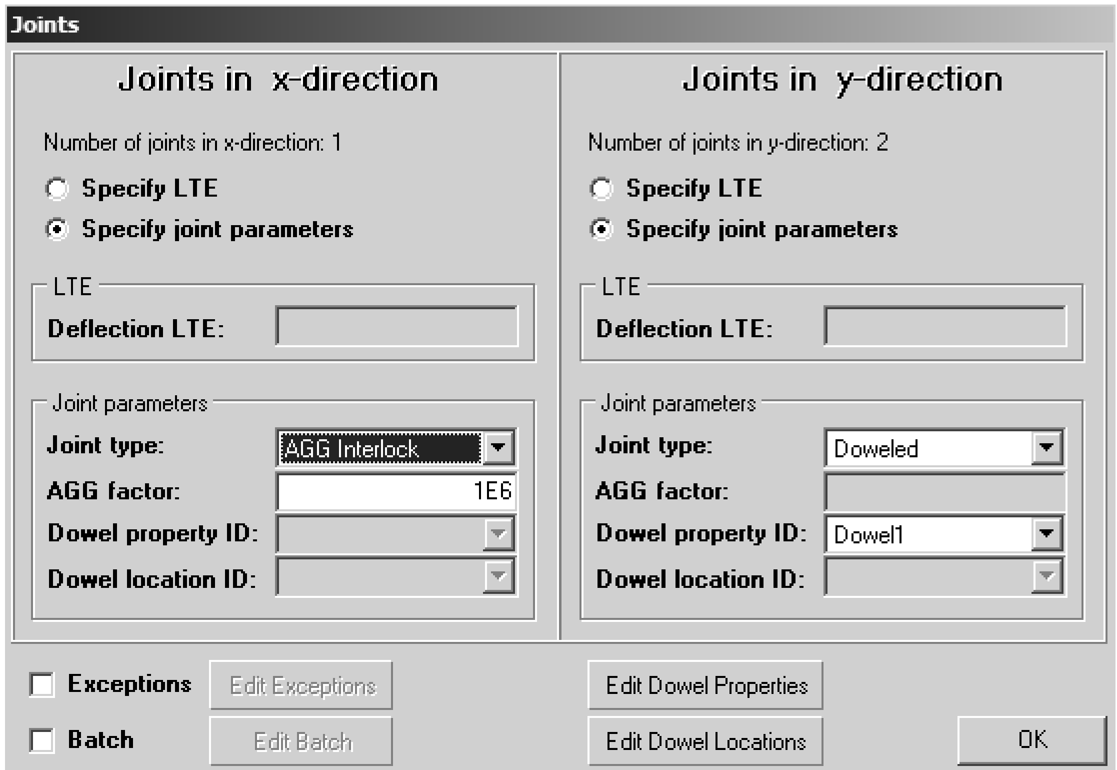


Figure 5: Joints Panel

For longitudinal joints, select **AGG Interlock** as the joint type. The value of the **AGG factor** parameter is dependent on the stiffness of the joint. For transverse joints, select **AGG Interlock** as the joint type for undoweled joints; select **Doweled** for the joint type for doweled joints. Example inputs for doweled joint are described in Example 8 of Part 2.

> **NOTE**
> For a pavement system with an area that differs from the rest of the pavement structure, select **Areas** from the main panel to define a special area. Example inputs for the area module are described in Examples 23 and 26 through 28 of Part 2.

Vehicle Load

To define and position the load on the pavement, perform the following procedure.

Step 1: Define the Axle Configuration Model and the Standard Configurations

Select **Load** from the main panel to open the load panel appears (see Figure 6).

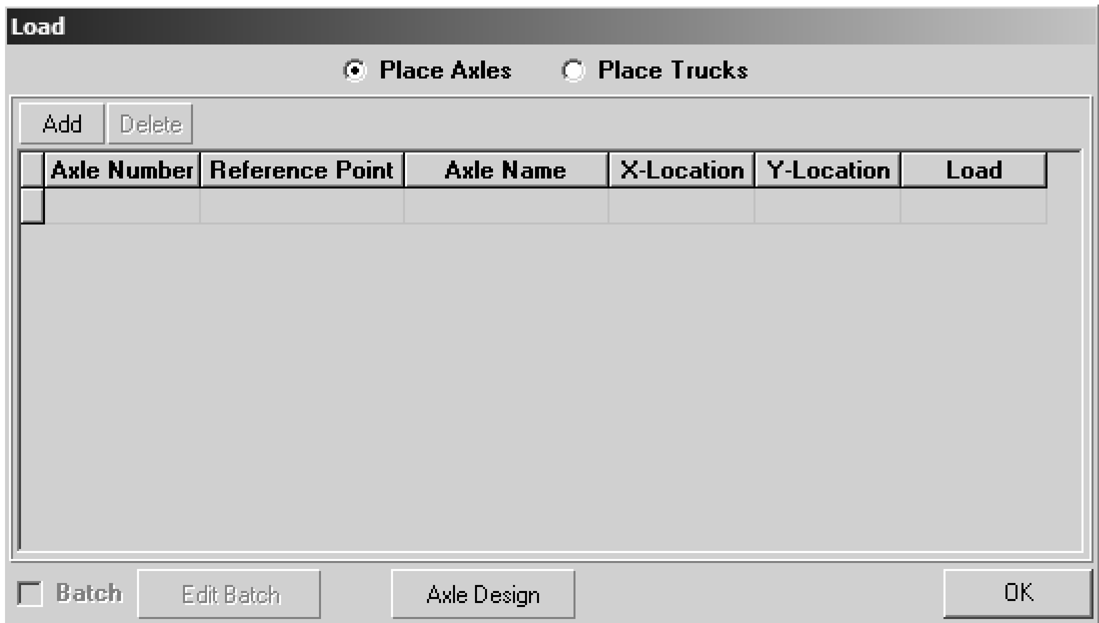


Figure 6: Load Panel

From the Load panel, select **Place Axles** and then click **Axle Design** to open the axle design panel (see Figure 7). ISLAB2000 is capable of modeling single, tandem, and tridem axles. Type an axle name into the **Axle Name** field, and then enter values for the data requested. If you do not have axle data specific to your application, use the standard inputs in Table 2.

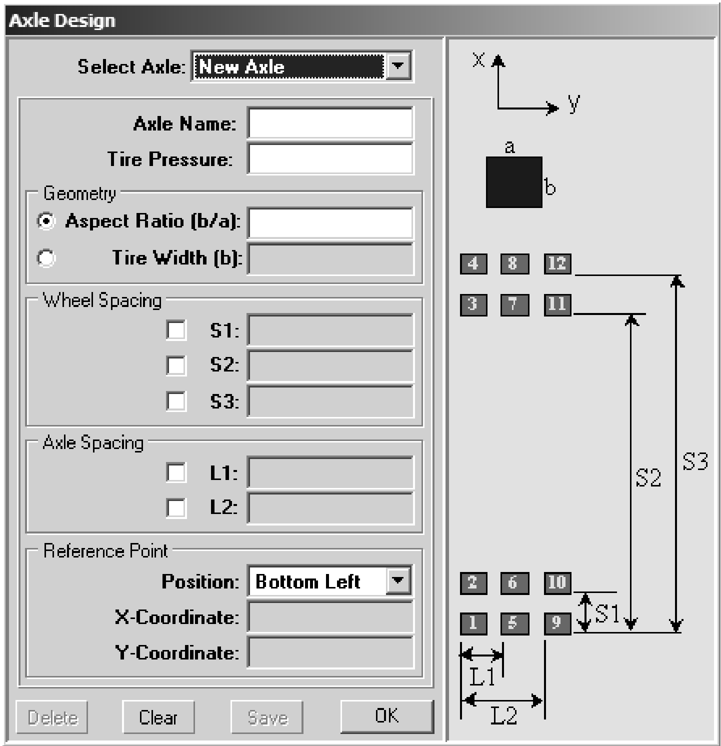


Figure 7: Axle Design Panel

Axle and wheel type	Loading parameters						
	Tire pressure (psi)	Tire aspect ratio	S1 (in.)	S2 (in.)	S3 (in.)	L1 (in.)	L2 (in.)
Single axle with single wheels	60-120	0.5	72	-	-	-	-
Single axle with dual wheels	60-120	0.5	12	72	84	-	-
Tandem axle with dual wheels	60-120	0.5	12	72	84	42	-
Tridem axle with dual wheels	60-120	0.5	12	72	84	42	84

Table 2: Standard Loading Parameters
(Source: Truck Driver's Guidebook, 6th Edition)

Bottom Left is the default reference point. In Figure 7 this point corresponds to loading number 1.

Step 2: Define the Truck Configuration Model

To model a truck loading, all axle components of the truck must already be defined. Select **Place Trucks** on the load panel, and then click **Truck Design**. The truck design panel appears (see Figure 8).

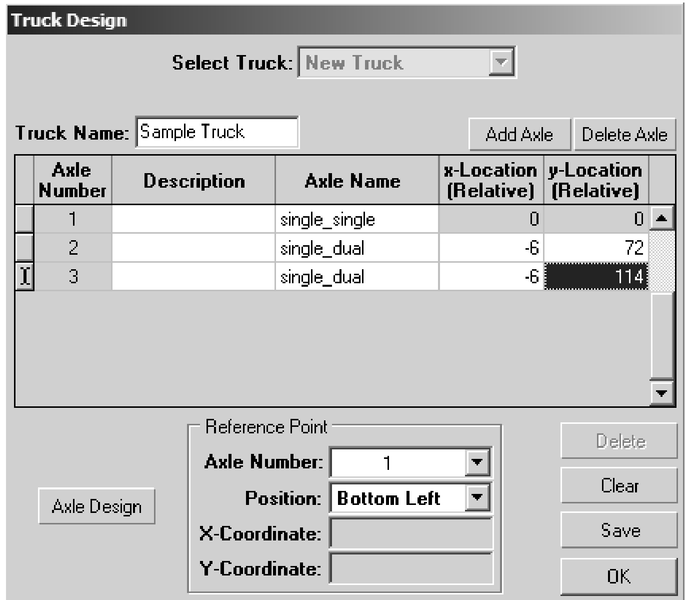


Figure 8: Truck Design Panel

Click **Add Axle** to add axles to the truck, and then select the axle name for each axle number corresponding to the axle type required for the truck. Next, enter x and y relative locations for each axle. Finally, select the reference axle of the truck. Axle number one is the default reference axle, but you can use other axles. The inputs used in Figure 8 result in a truck configuration as illustrated in Figure 9.

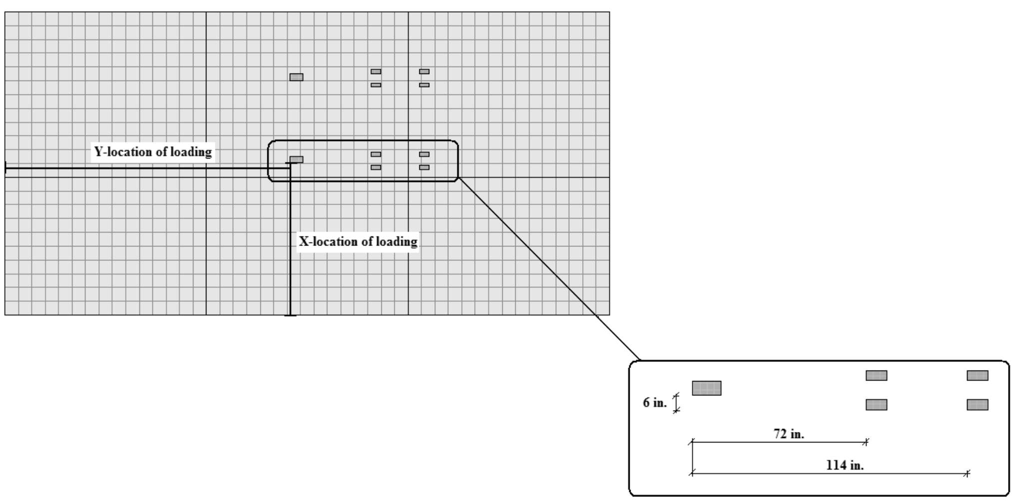


Figure 9: Illustration of Truck Configuration and Load Location

Step 3: Define the Load Positioning System

After completing either axle design or truck design process, the load is to be positioned by identifying the X and Y locations for the axle or truck (see Figure 9).

Layer Temperature

ISLAB2000 allows you to account for the impact of temperature through two options: *linear thermal gradients* and *non-linear temperature profile*.

- **Linear Thermal Gradient:** The linear thermal gradient is the temperature differential between the top and bottom of the PCC slab divided by the PCC thickness. To define a linear thermal gradient, select **Temperature** from the main panel. The layers temperature properties panel appears (see Figure 10). In the layers temperature properties panel, select the **Perform Temperature Analysis** check box, and then select **Linear** for the type of thermal gradient. In the **Difference** field, enter the temperature differential (in degrees Fahrenheit), which is equal to the thermal gradient multiplied by the PCC thickness.

  NOTE
  The positive thermal gradient or daytime gradient indicates that the top layer is warmer than the bottom layer, while negative thermal gradient or nighttime gradient indicates that the bottom layer is warmer than the top layer.

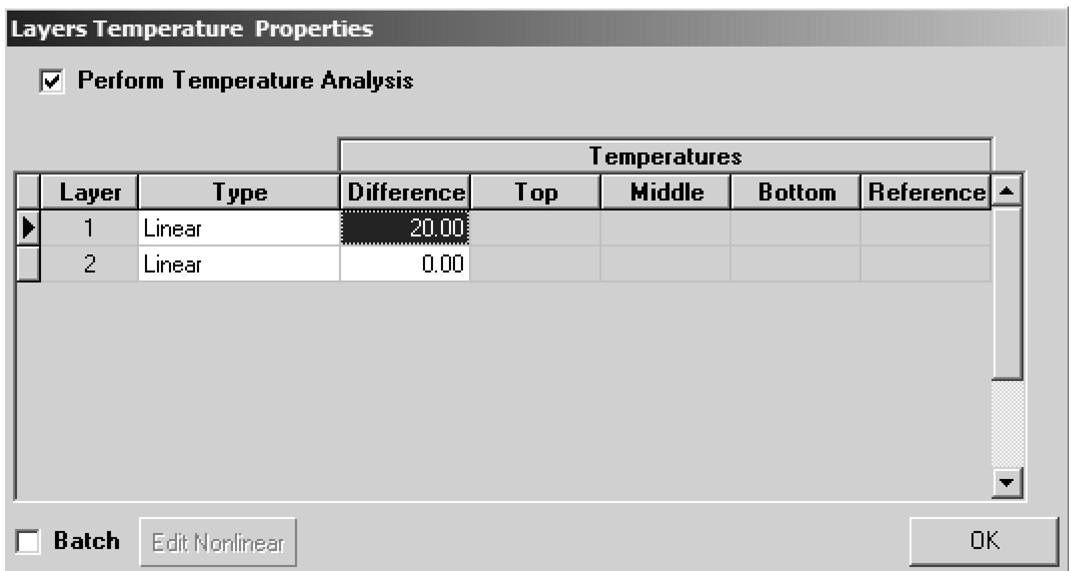


Figure 10: Layers Temperature Properties Panel

- **Non-linear Temperature Profile:** This option of temperature analysis requires temperatures from at least three different depths. First, select **Nonlinear** for the analysis type for layer 1 (see Figure 11), and then click on **Edit Nonlinear**.

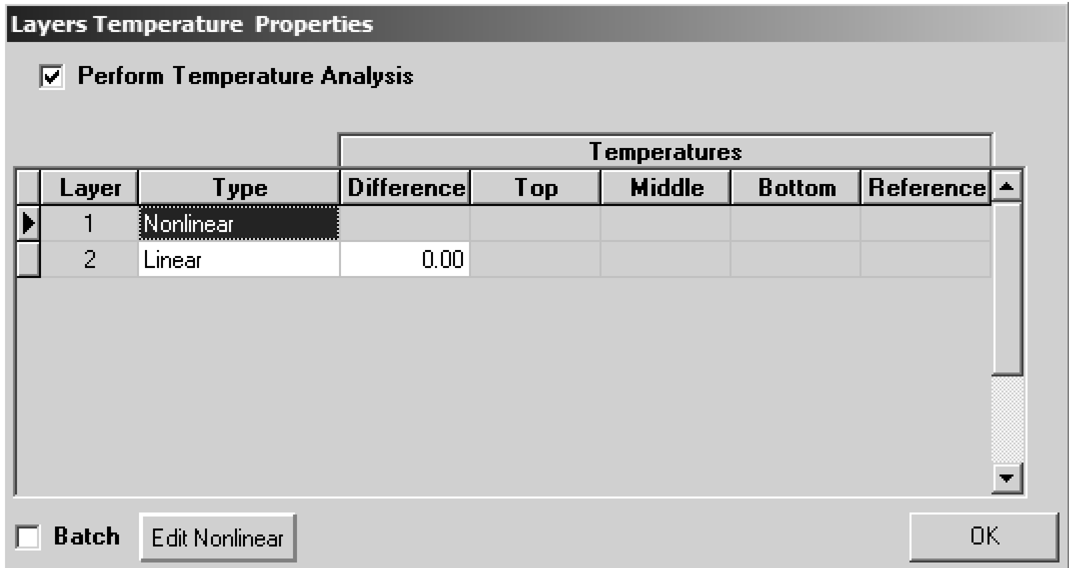


Figure 11: Layers Temperature Properties Panel

The edit nonlinear temperature distributions appear (see Figure 12). Type the temperature at each depth. If more temperature nodes are available, click **Insert Temperature Node** to add more temperatures.

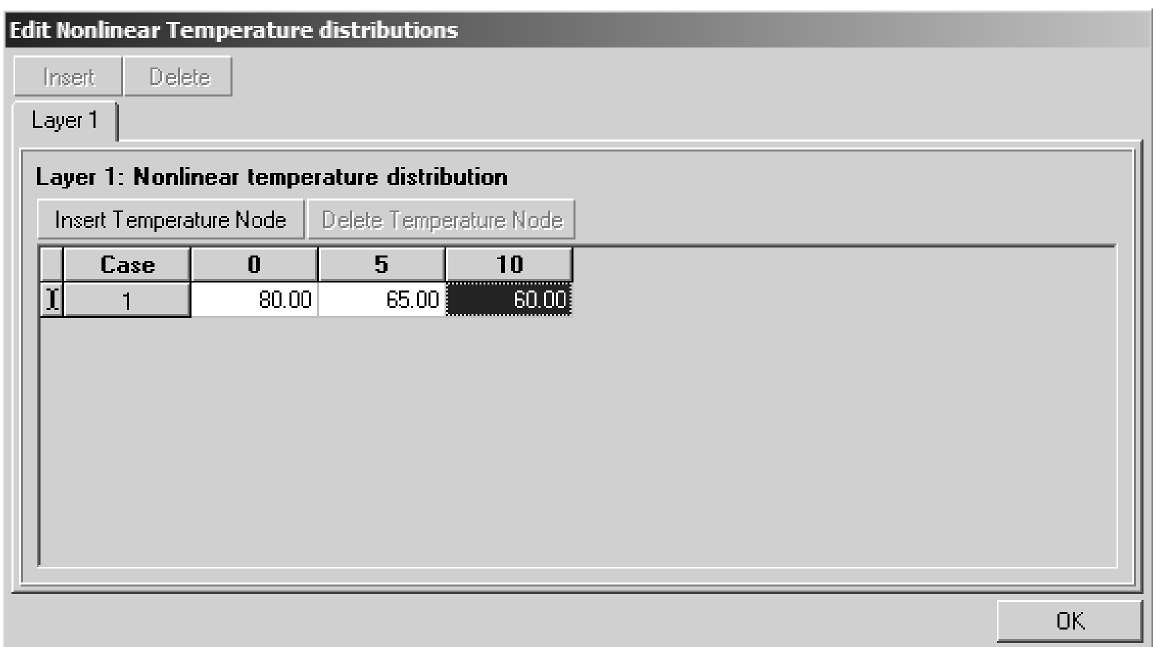
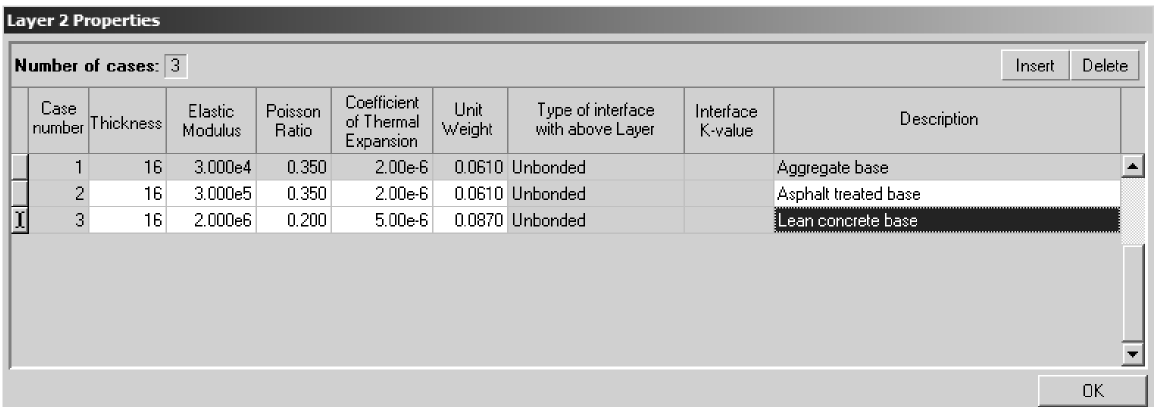


Figure 12: Edit nonlinear temperature distributions panel

Batch Application

Through batch application, ISLAB2000 is capable of performing multiple analyses for structural conditions, loading levels, and temperature conditions. Batch application is available in three structural modules: Layers, Subgrade, and Joints.

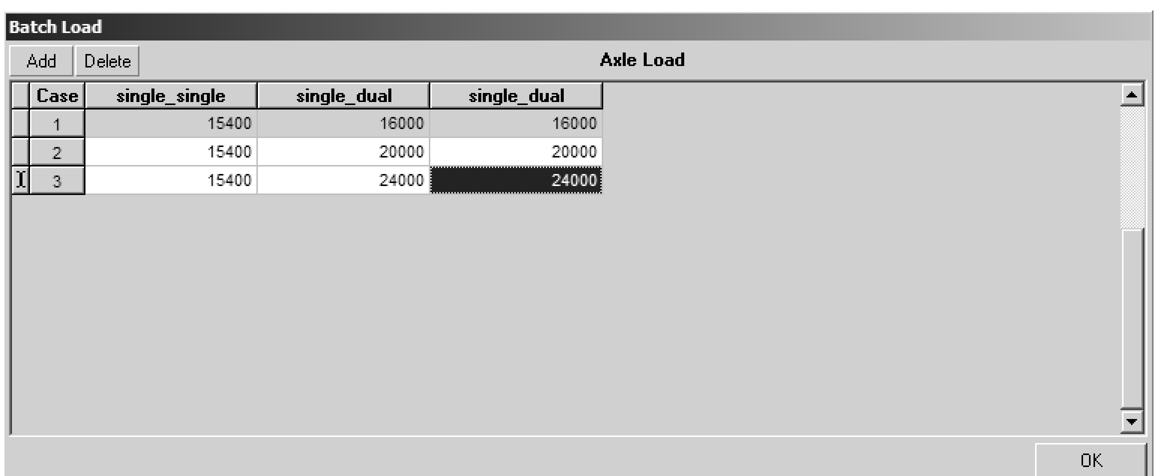
- **Layers module:** Batch application allows for adding cases for each layer. The added cases could have thickness, elastic modulus, Poisson's ratio, CTE, unit weight, and also interface condition between two layers different from the original case. Figure 13 illustrates an example of batch application for the layers module.



Case number	Thickness	Elastic Modulus	Poisson Ratio	Coefficient of Thermal Expansion	Unit Weight	Type of interface with above Layer	Interface K-value	Description
1	16	3.000e4	0.350	2.00e-6	0.0610	Unbonded		Aggregate base
2	16	3.000e5	0.350	2.00e-6	0.0610	Unbonded		Asphalt treated base
3	16	2.000e6	0.200	5.00e-6	0.0870	Unbonded		Lean concrete base

Figure 13: Batch Application for Layers Module

- **Multiple analyses for loading levels:** For the load module, batch application allows for analysis of several load levels at the same time. Figure 14 illustrates an example of batch application for the load module.



Case	single_single	single_dual	single_dual
1	15400	16000	16000
2	15400	20000	20000
3	15400	24000	24000

Figure 14: Batch Application for Load Module

- **Multiple analyses for temperature conditions:** Batch application allows for analysis of several temperature conditions at the same time. Figures 15 and 16 illustrate examples of batch application for linear thermal gradient and non-linear temperature profiles.

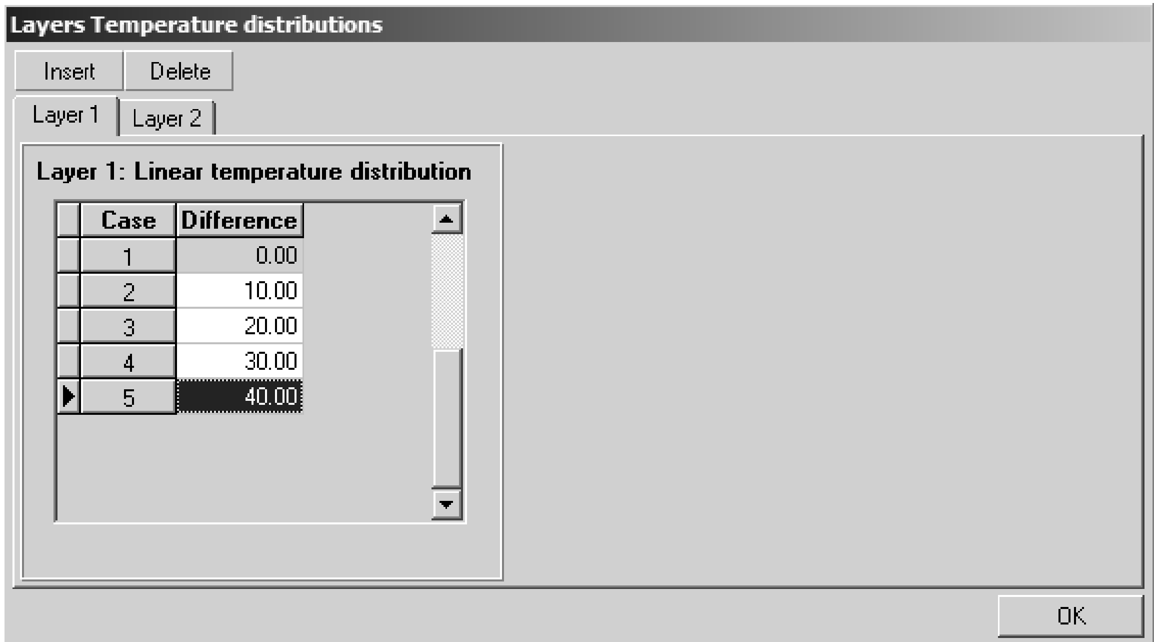


Figure 15: Batch Application for Temperature Module (linear)

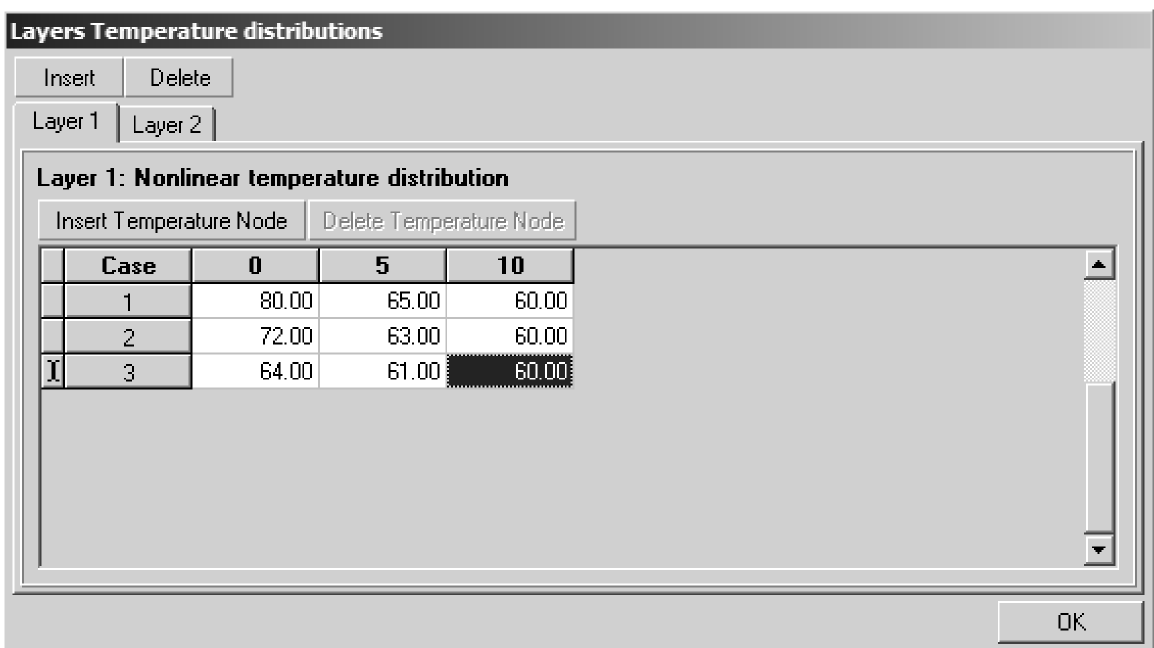


Figure 16: Batch Application for Temperature Module (nonlinear)

Analysis Results

To generate results, first click **Generate Input Files** and then click **Run ISLAB2000** from the **Run** menu item. To view results in graphical form, click **View Analysis Results** from the **Run** menu item (see Figure 17).

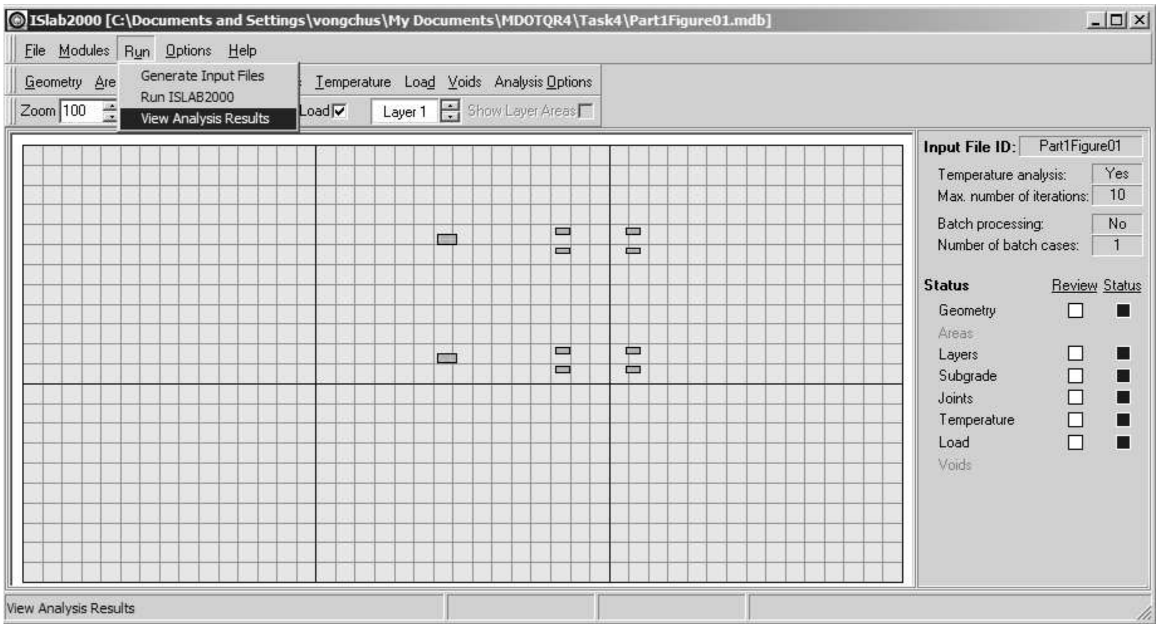


Figure 17: View Analysis Results on Run Menu

Stresses and Deflection

Figures 18 and 19 shows typical graphical representations of stresses and deflection in ISLAB2000. As shown in the figure 18, the following types of stress contours are available for each layer and for top and bottom of the layer:

- X Stresses (transverse stresses)
- Y Stresses (longitudinal stresses)
- XY Stresses (shear stresses)
- Principal Stresses

Figure 19 shows a deflection contour based on the stresses shown in Figure 18. To view a deflection contour, select **Deflection** from the third pull down menu shown in Figure 17.

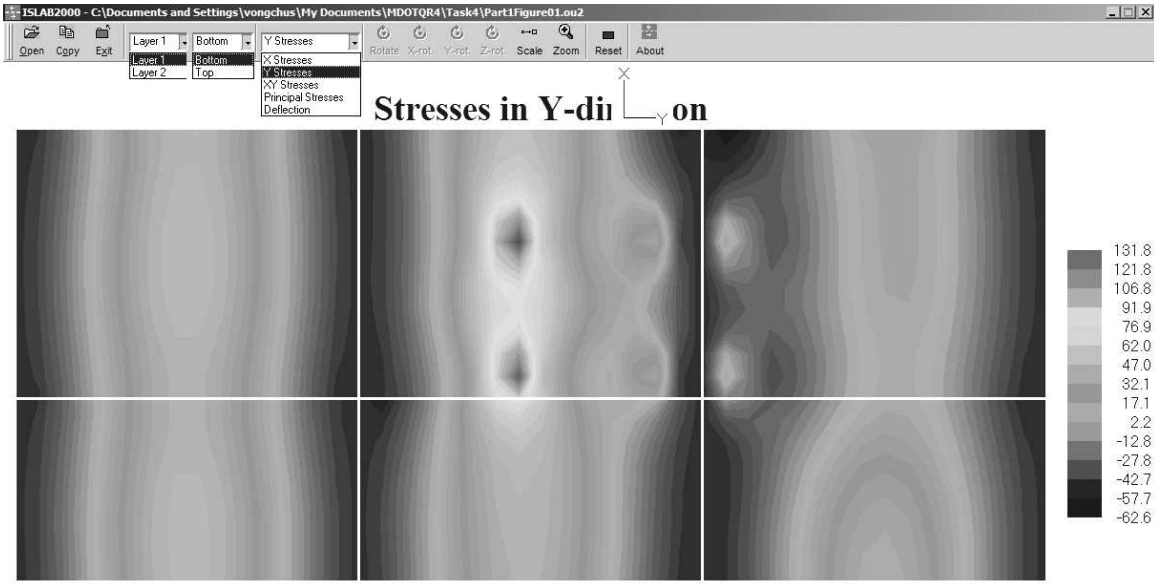


Figure 18: Stress Contour Obtained from ISLAB2000

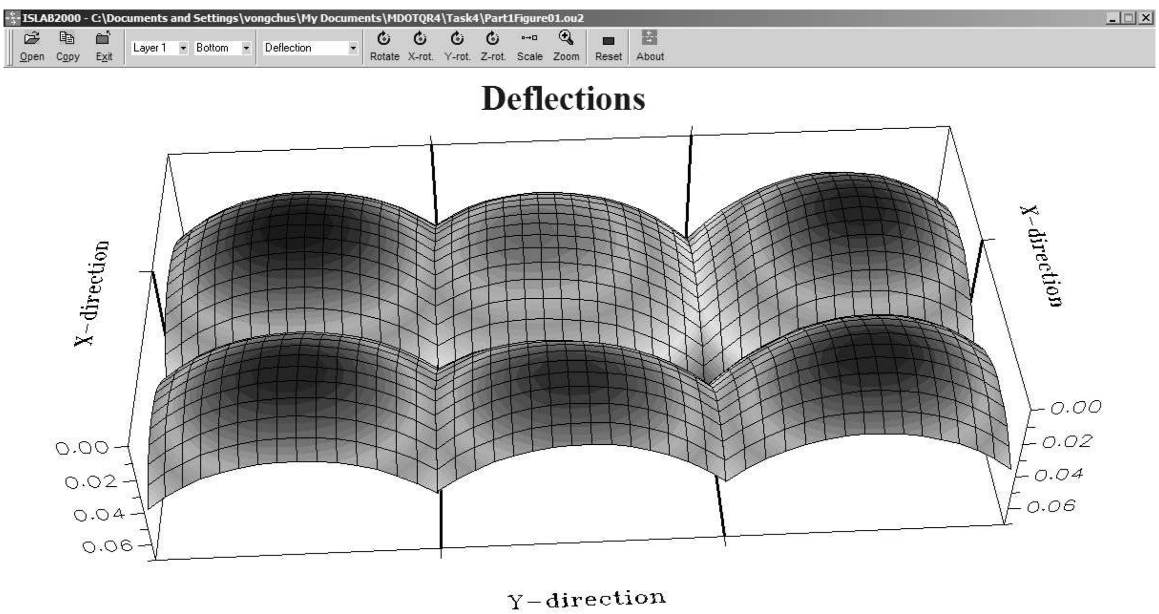


Figure 19: Deflection Contour Obtained from ISLAB2000

Part II: Examples

Example 1:
Interior Loading of a Single Slab

Problem statement

Determine the maximum deflection and maximum stress at the bottom of the PCC slab for Westergaard's interior loading condition.

Given

Concrete elastic modulus	=	4×10^6	psi
Concrete Poisson's ratio	=	0.15	
Slab thickness	=	10	in.
Slab dimension	=	144 x 180	in^2
Mesh size	=	12 x 12	in^2 (medium)
k-value	=	100	psi/in.
Tire contact area	=	7.5 x 15	in^2
Wheel load	=	10,000	lbs

Problem illustration

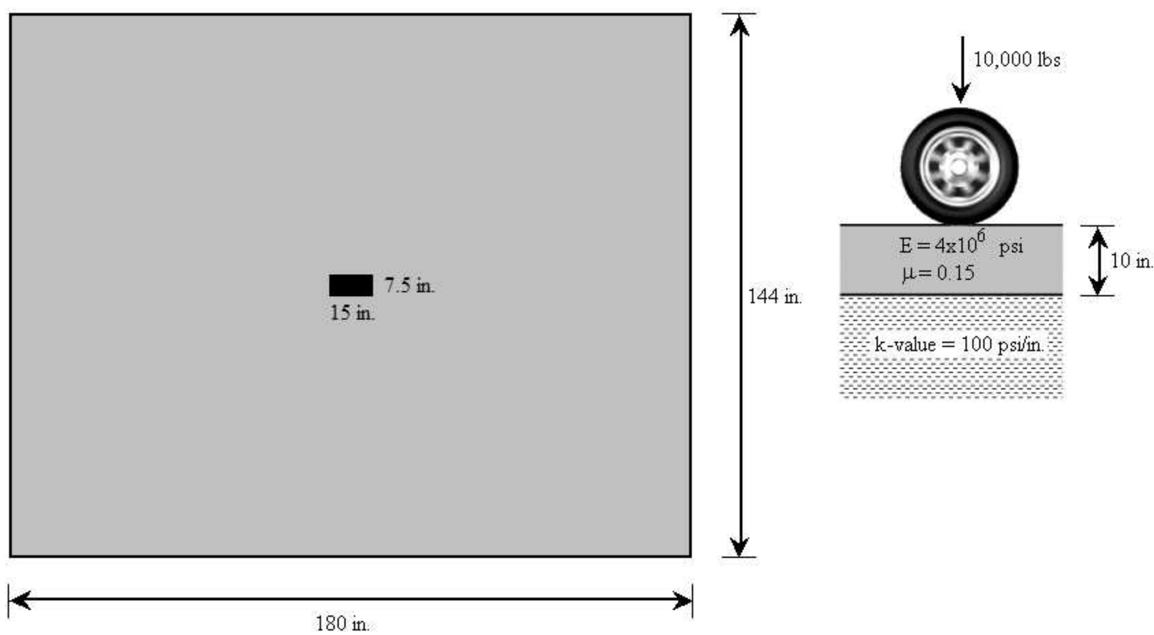


Figure E1-1: Problem Ilustration

Solution

Geometry Module

(see Figure E1-2)

Step 1: Click **Geometry** on the main panel to open the geometry panel.

Step 2: On the geometry panel, click **Insert** on the **X-direction** side, and then type the slab length, which is 144 in. for this example.

Step 3: Click **Insert** on the **Y-direction** side, and then type the slab length, which is 180 in. for this example.

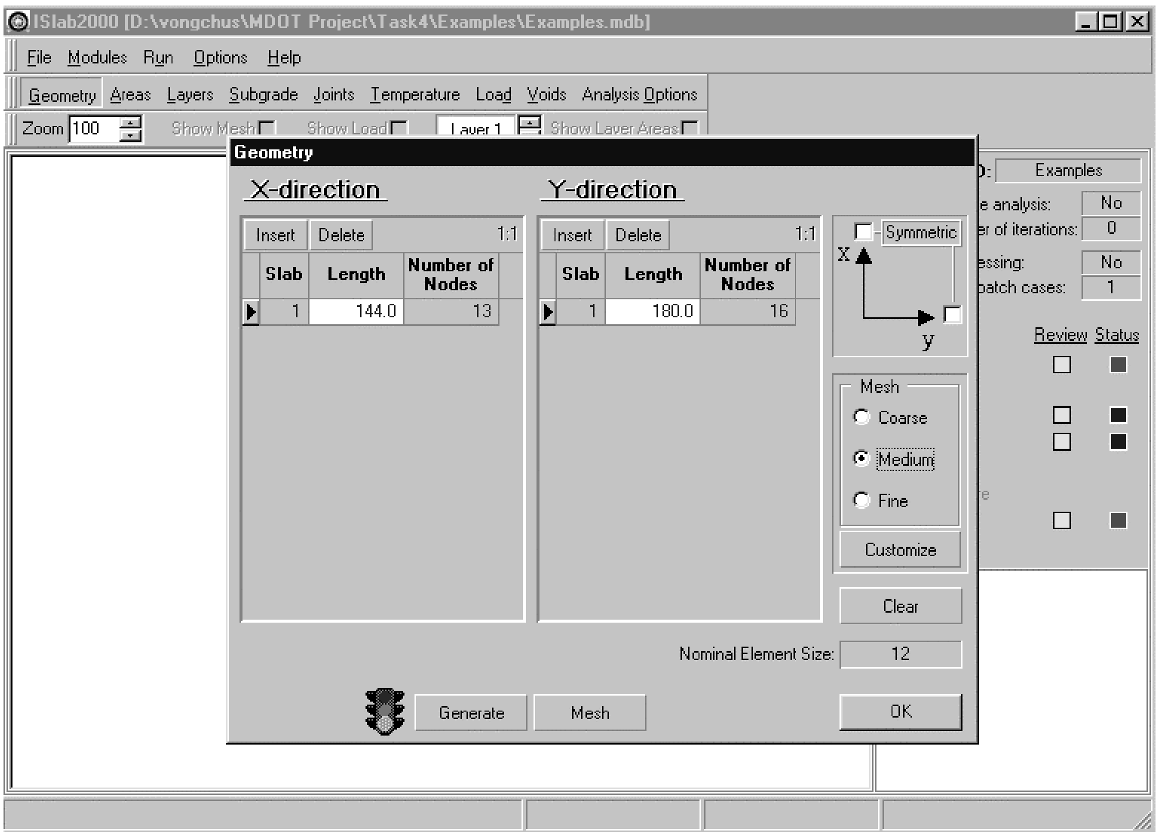


Figure E1-2: Edit inputs for the geometry module

Step 4: On the right side of the geometry panel, select the **Medium** radio button to select the medium mesh size.

Step 5: At the bottom of the panel, click **Generate** to generate the inputs to the input file, and then click **OK** to close the geometry panel.

Layers Module

(see Figure E1-3)

Step 1: Click **Layers** on the main panel to open the layers panel.

Step 2: On the layers panel, type the inputs as identified in the problem statement.

Step 3: Click **OK** to close the layers panel.

Subgrade Module

(see Figure E1-4)

Step 1: Click **Subgrade** on the main panel to open the subgrade panel.

Step 2: On the subgrade panel, type the inputs as identified in the problem statement.

Step 3: Click **OK** to close the subgrade panel.

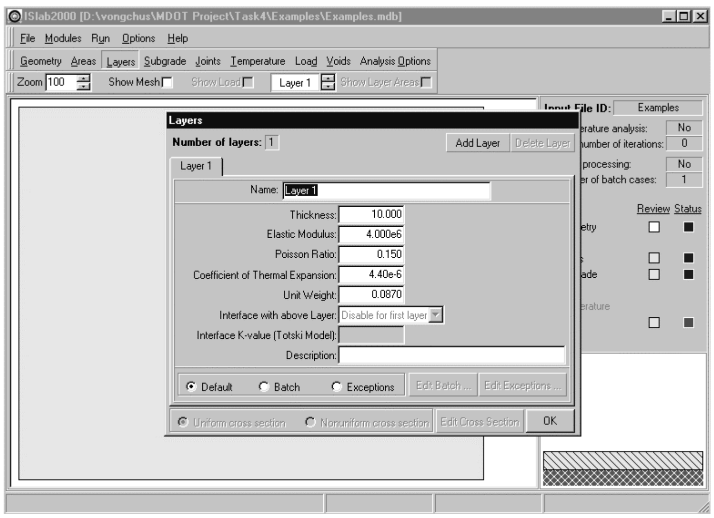


Figure E1-3: Edit Inputs for the Layers Module

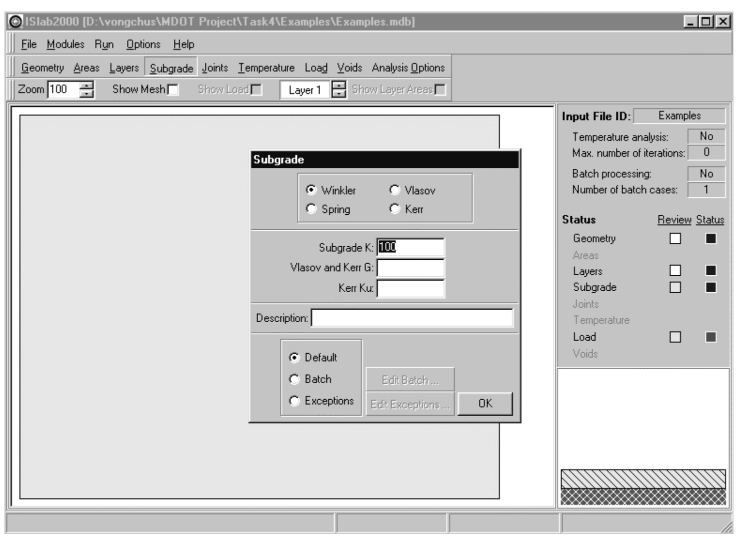


Figure E1-4: Edit Inputs for the Subgrade Module

Load Module

(see Figures E1-5 and E1-6)

Step 1: Click **Load** on the main panel to open the load panel.

Step 2: On the load panel, click **Axle Design** to open the axle design panel.

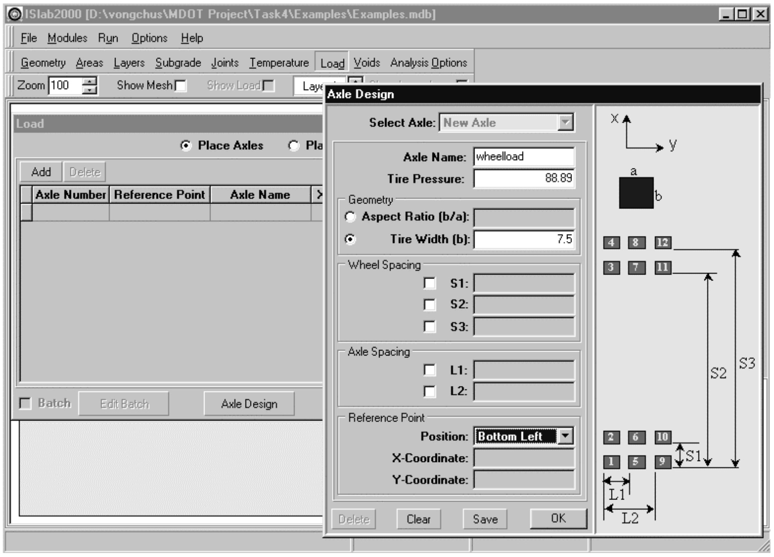


Figure E1-5: Edit inputs for the load module

Step 3: On the axle design panel, type "wheel load" in the **Axle Name** field to name the axle.

Step 4: Type the tire pressure in the **Tire Pressure** field. The tire pressure of the wheel load can be computed as shown below:

$$Tire\ Pressure = \frac{Wheel\ Load}{Contact\ Area} = \frac{10{,}000\ lbs}{7.5\ in. \times 15\ in.} = 88.89\ psi$$

Step 5: Type the tire width (7.5 in. for this example), in the **Tire Width** field.

Step 6: Select **Bottom Left** for the reference point position.

Step 7: Click **OK** to close the axle design panel.

Step 8: On the load panel (see Figure E1-6), click **Add** to add an axle.

Step 9: In the **Axle Name** field, select "wheel load."

Step 10: Enter an X-location and a Y-location to locate the wheel load. X-location and Y-location for interior loading conditions can be computed as shown below:

$$X-location=\frac{Slab\ width}{2}-\frac{wheel\ load\ width}{2}.$$

$$=\frac{144}{2}-\frac{7.5}{2}=68.25\ in$$

$$Y-location=\frac{Slab\ length}{2}-\frac{wheel\ load\ length}{2}.$$

$$=\frac{180}{2}-\frac{15}{2}=82.5\ in$$

Step 11: Enter the load for the wheel load, which is 10,000 lbs for this example.

Step 12: Click **OK** to close the load panel.

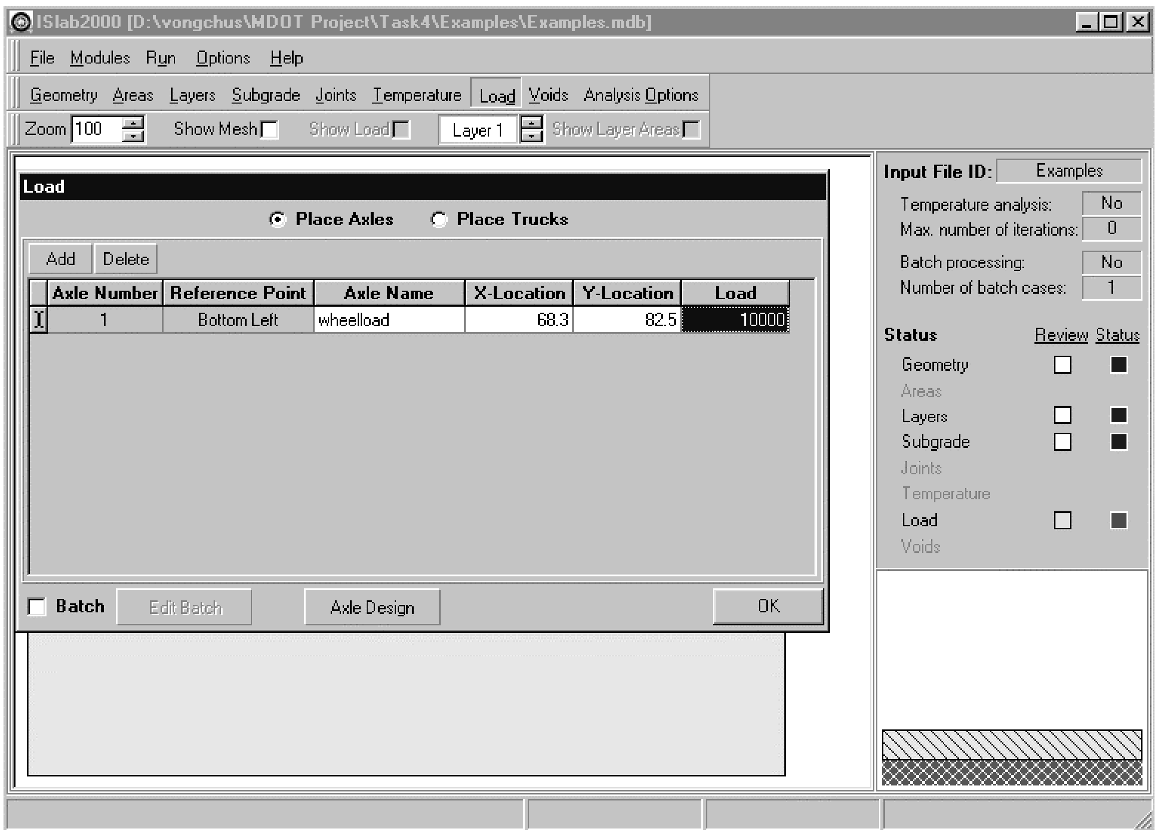


Figure E1-6: Edit Inputs for the Load Module (continued)

At this stage, all inputs are completed. If all the inputs are correct, the color of all status boxes will change from red to blue. The main panel should display the pavement structure, loading condition, and mesh as shown in Figure E1-7.

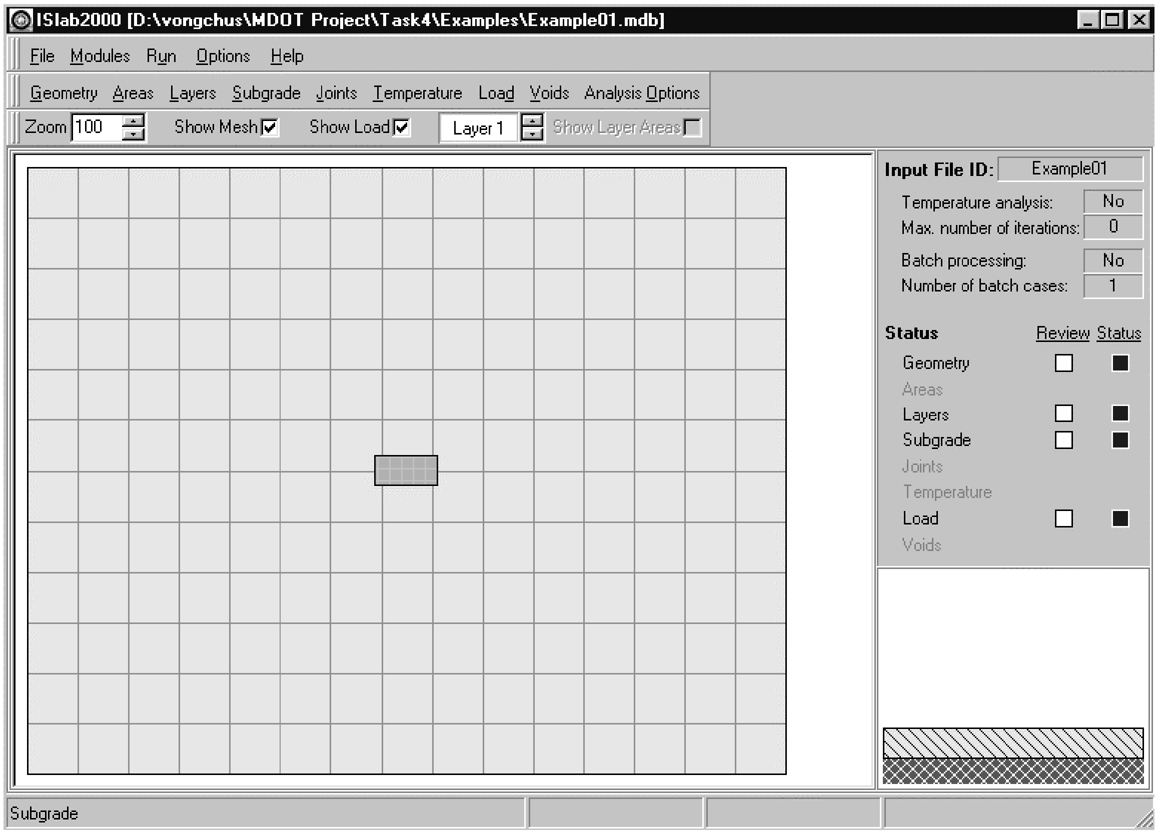


Figure E1-7: Main Panel After the Completion of Inputs

Analysis Results

Maximum transverse stress at the bottom of the PCC slab (see Figure E1-8)	=	140.6 psi
Maximum longitudinal stress at the bottom of the PCC slab (see Figure E1-9)	=	123.4 psi
Maximum deflection of the PCC slab (see Figure E1-10)	=	0.00796 in.

NOTE
Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

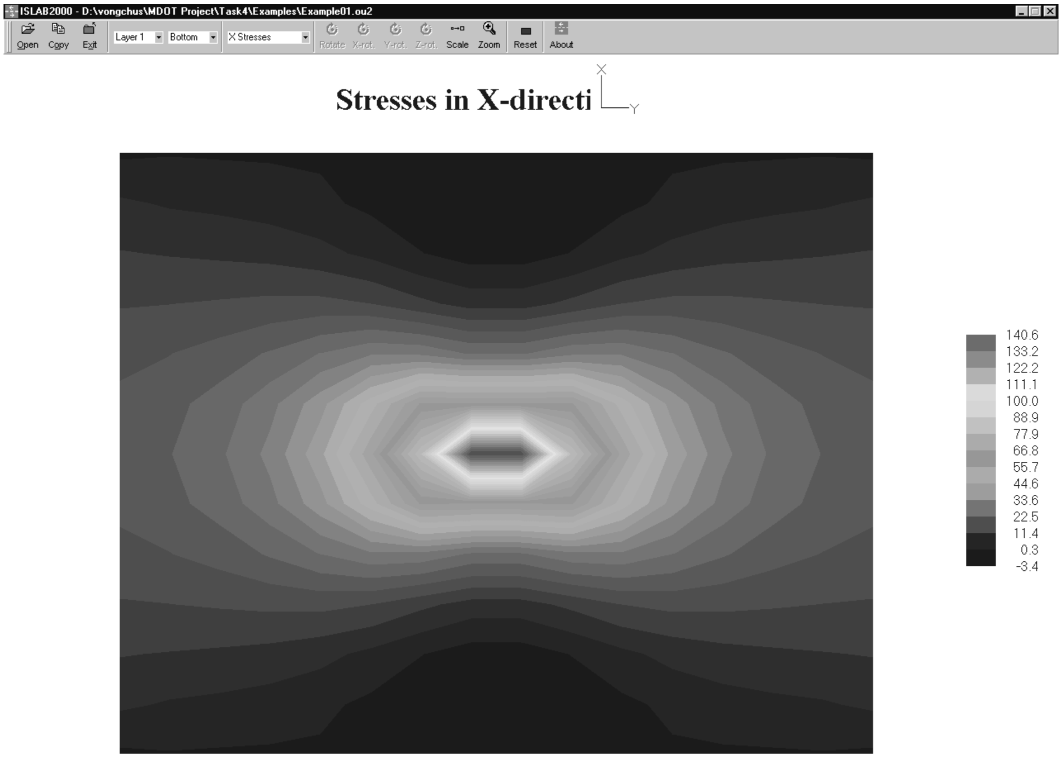


Figure E1-8: Transverse Stress at the Bottom of the PCC Slab

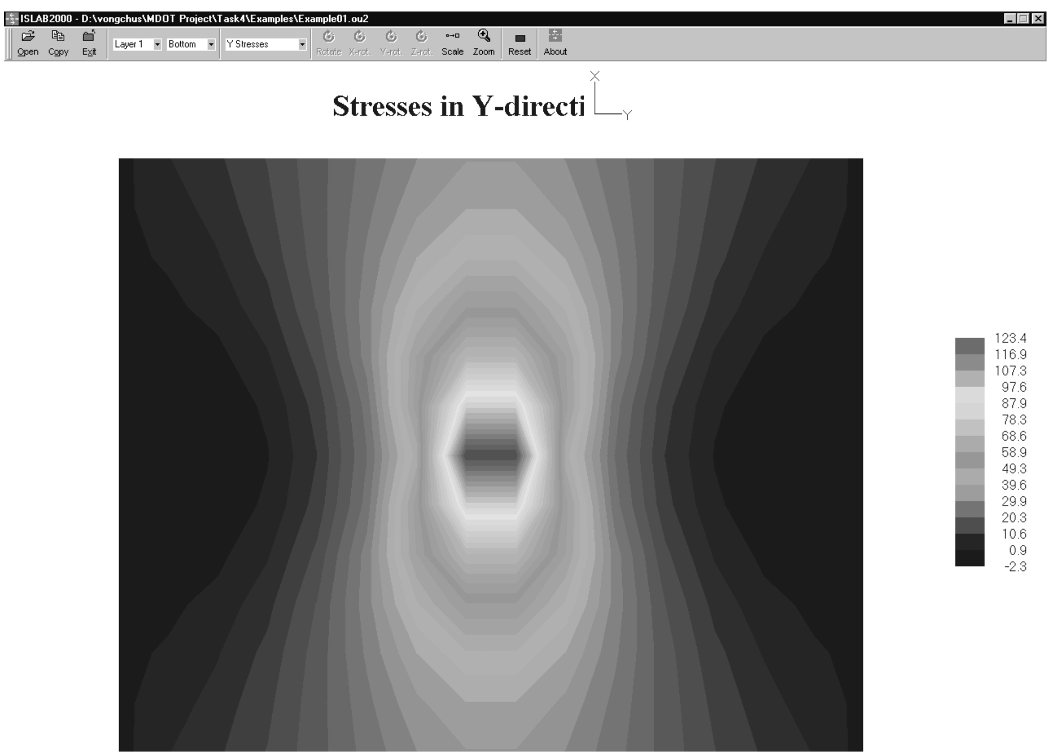


Figure E1-9: Longitudinal Stress at the Bottom of the PCC Slab

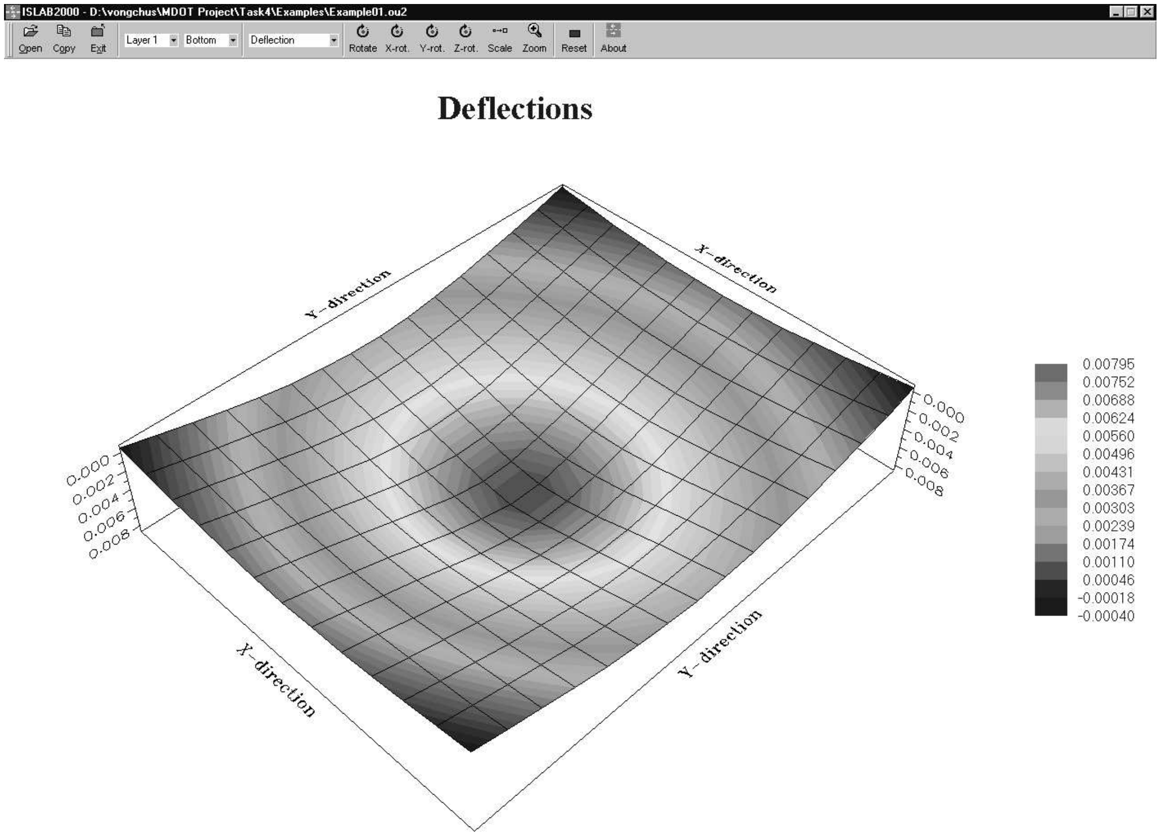


Figure E1-10: Deflection of the PCC Slab

Example 2:
Edge Loading of a Single Slab

Problem Statement

Determine maximum deflection and stress for the PCC slab using Westergaard's edge loading condition.

Given

Concrete elastic modulus	=	4×10^6	psi
Concrete Poisson's ratio	=	0.15	
Slab thickness	=	10	in.
Slab dimension	=	144 x 180	in^2
Mesh size	=	12 x 12	in^2 (medium)
k-value	=	100	psi/in.
Tire contact area	=	7.5 x 15	in^2
Wheel load	=	10,000	lbs

Problem Illustration

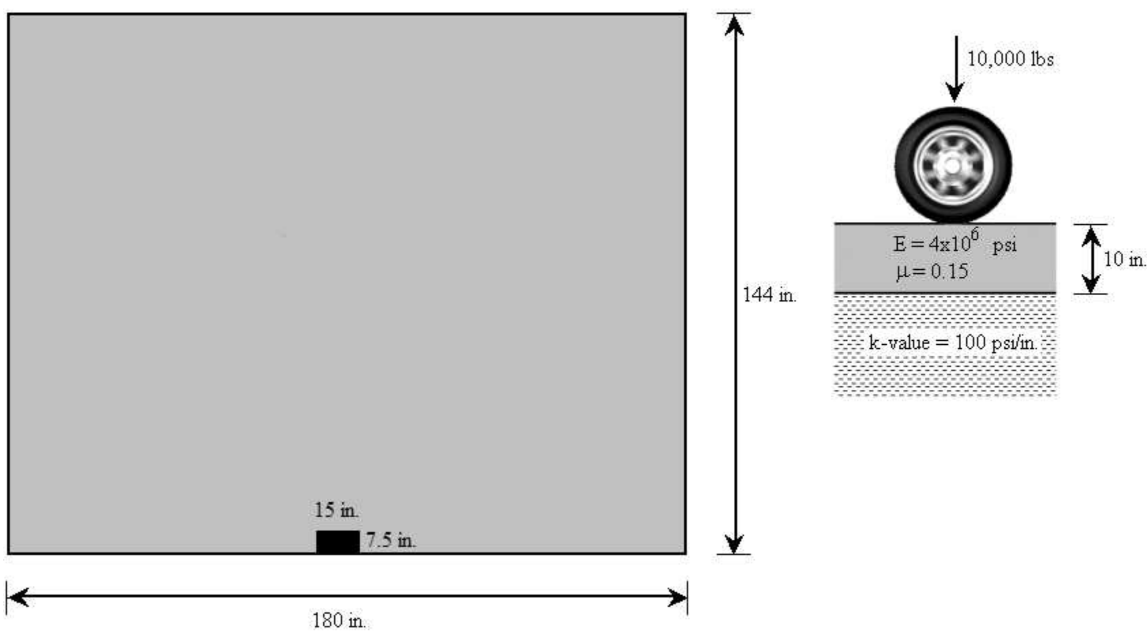


Figure E2-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 1.

Layers Module

Use this module from Example 1.

Subgrade Module

Use this module from Example 1.

Load Module

(see Figures E2-2)

Step 1: Follow steps 1 through 9 from the load module in Example 1.

Step 2: Enter an X-location and a Y-location to locate the wheel load. The X-location and Y-location for edge loading condition can be computed as shown below:

$$X - location = 0$$

$$Y - location = \frac{Slab\ length}{2} - \frac{wheel\ load\ length}{2}.$$

$$= \frac{180}{2} - \frac{15}{2} = 82.5\ in$$

Step 3: Type the load for the wheel load, which is 10,000 lbs for this example.

Step 4: Click **OK** to close the load panel.

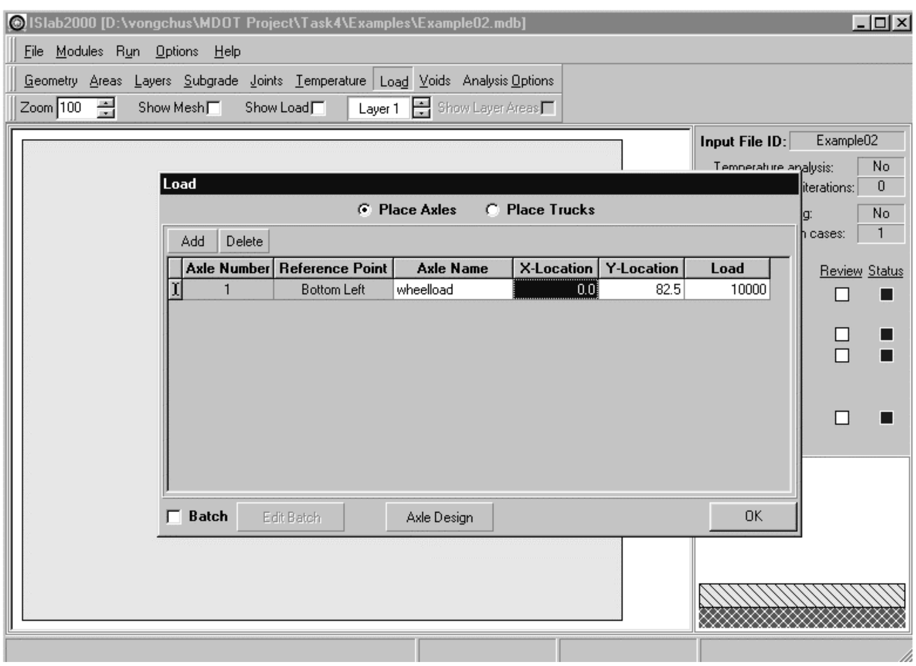


Figure E2-2: Edit Inputs for the Load Module

The main panel should display the pavement structure, loading condition, and meshing as shown in Figure E2-3.

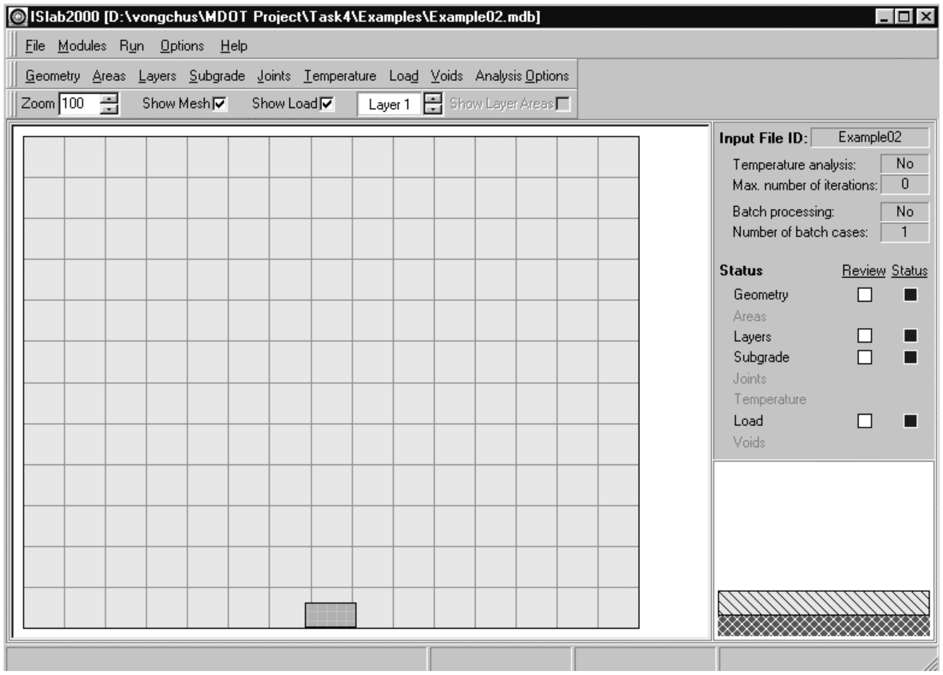


Figure E2-3: Main Panel After the Completion of Inputs

Analysis Results

Maximum transverse stress at the bottom of the PCC slab (see Figure E2-4) = 37.4 psi

Maximum longitudinal stress at the bottom of the PCC slab (see Figure E2-5) = 245.5 psi

Maximum deflection of the PCC slab (see Figure E2-6) = 0.02514 in.

NOTE
Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

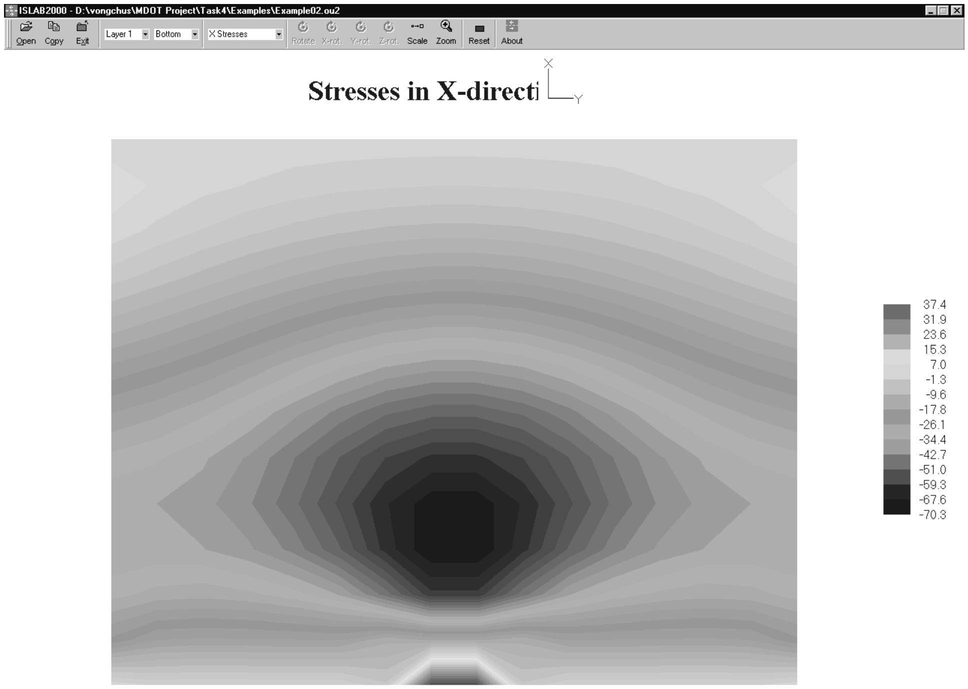


Figure E2-4: Transverse Stress at the Bottom of the PCC Slab

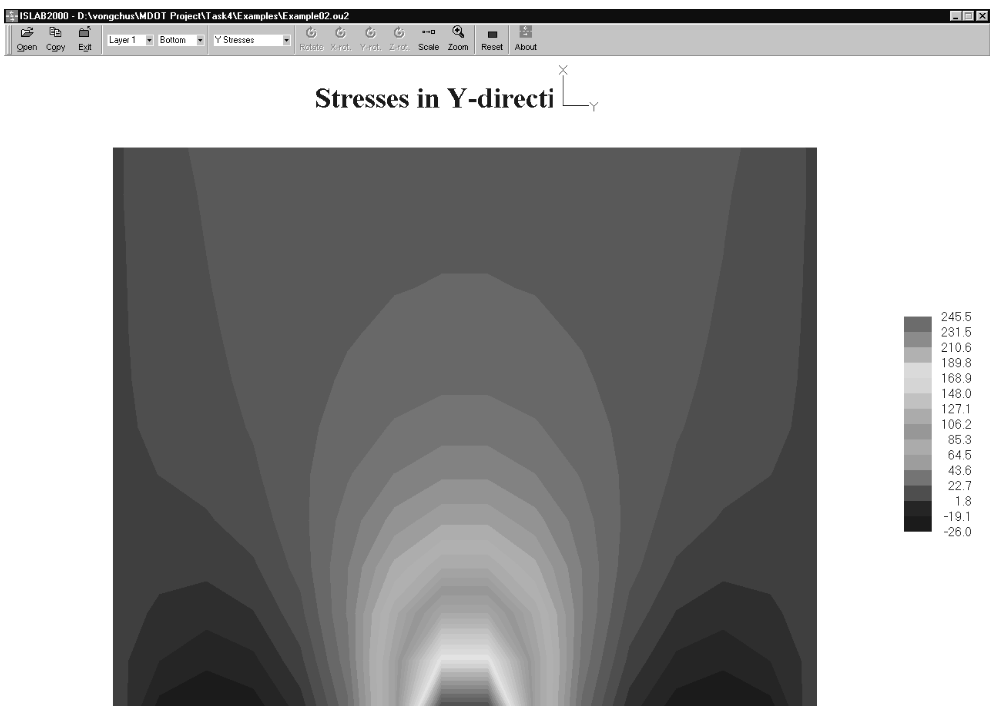


Figure E2-5: Longitudinal Stress at the Bottom of the PCC Slab

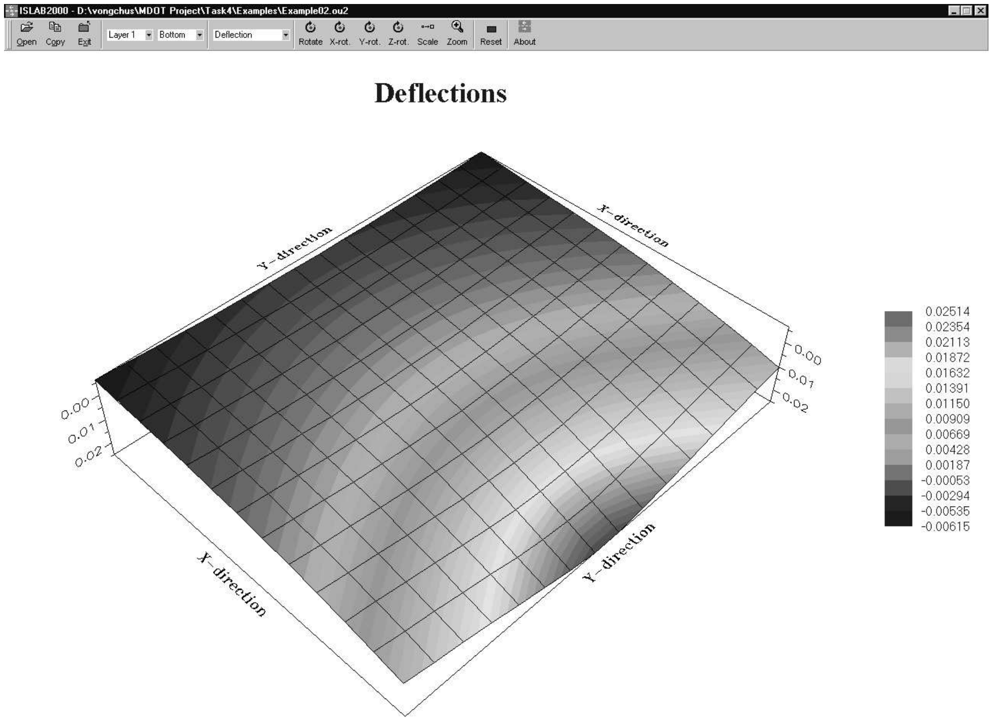


Figure E2-6: Deflection of the PCC Slab

Example 3:
Corner Loading of a Single Slab

Problem Statement

Determine maximum deflection and stress at the top of the PCC slab for Westergaard's corner loading condition. Then, compare the results from interior and edge loading conditions in Examples 1 and 2.

Given

Concrete elastic modulus	=	4×10^6	psi
Concrete Poisson's ratio	=	0.15	
Slab thickness	=	10	in.
Slab dimension	=	144 x 180	in^2
Mesh size	=	12 x 12	in^2 (medium)
k-value	=	100	psi/in.
Tire contact area	=	7.5 x 15	in^2
Wheel load	=	10,000	lbs

Problem Illustration

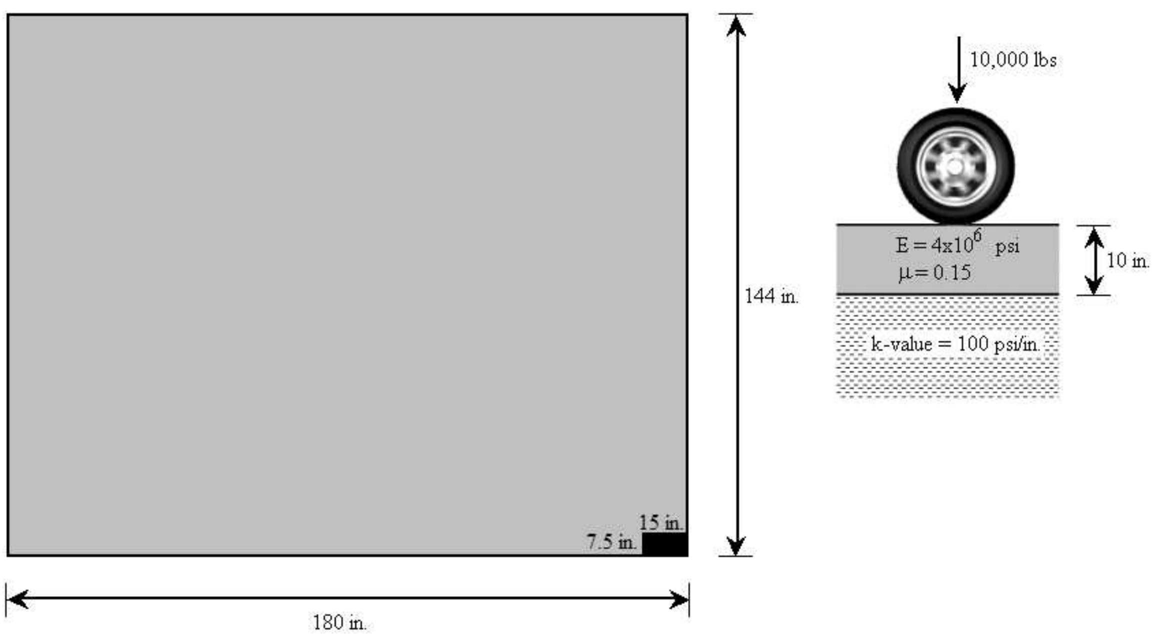


Figure E3-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 1.

Layers Module

Use this module from Example 1.

Subgrade Module

Use this module from Example 1.

Load Module

(see Figures E3-2)

Step 1: Follow steps 1 through 9 from the load module in Example 1.

Step 2: Type an X-location and a Y-location to locate the wheel load. The X-location and Y-location for corner loading condition can be computed as shown below:

$$X - location = 0$$

$$Y - location = Y - direction\ slab\ length - wheel\ load\ length.$$

$$= 180 - 15 = 165\ in$$

Step 3: Enter the load for the wheel load, which is 10,000 lbs for this example.

Step 4: Click **OK** to close the load panel.

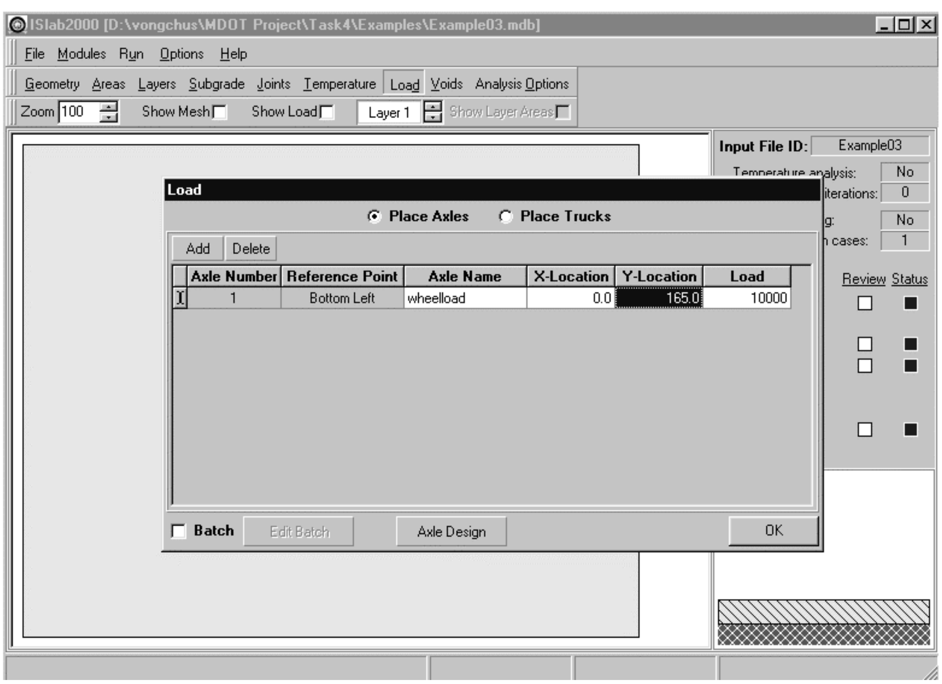


Figure E3-2: Edit Inputs for the Load Module

The main panel should display the pavement structure, loading condition, and meshing as shown in Figure E3-3.

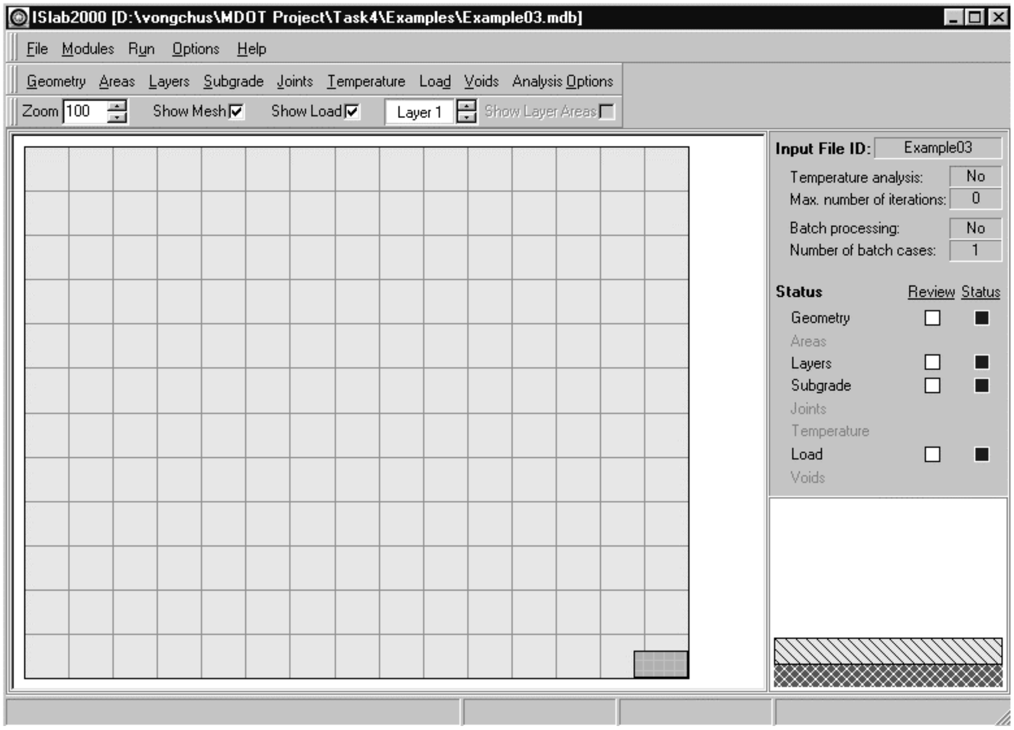


Figure E3-3: Main Panel After the Completion of Inputs

Analysis Results

Maximum transverse stress at the top of the PCC slab = 137.3 psi
(see Figure E3-4)

Maximum longitudinal stress at the top of the PCC slab = 131.1 psi
(see Figure E3-5)

Maximum stress at the top of the PCC slab = 195.5 psi
(see Figure E3-6)

Maximum deflection of the PCC slab = 0.0574 in.
(see Figure E3-7)

Comparison of stresses and deflections from the three loading conditions are illustrated in Figures E3-8 and E3-9.

NOTE
Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

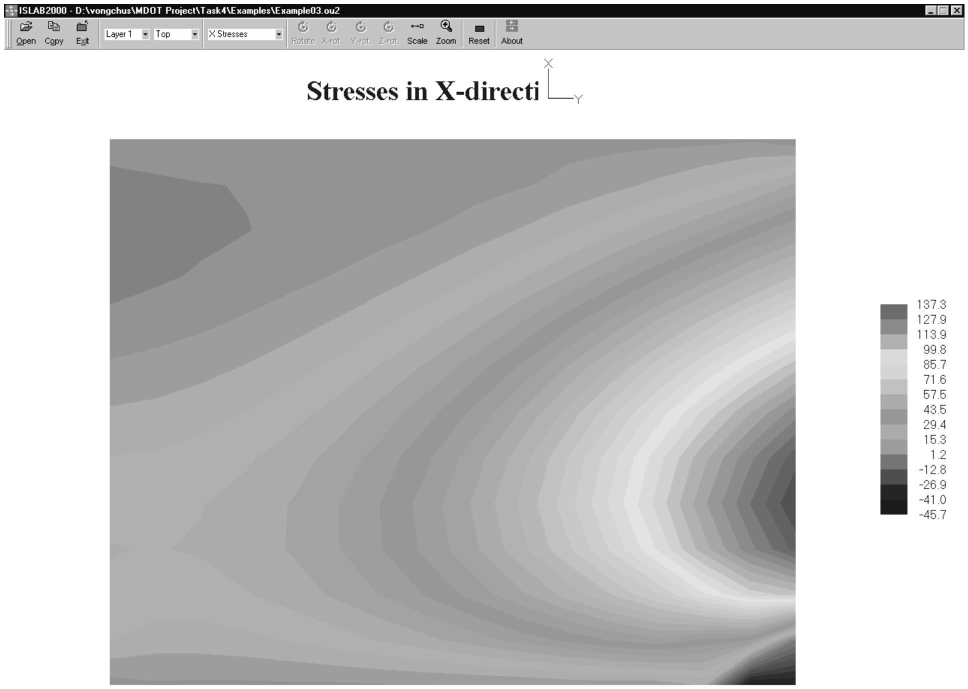


Figure E3-4: Transverse Stress at the Top of the PCC Slab

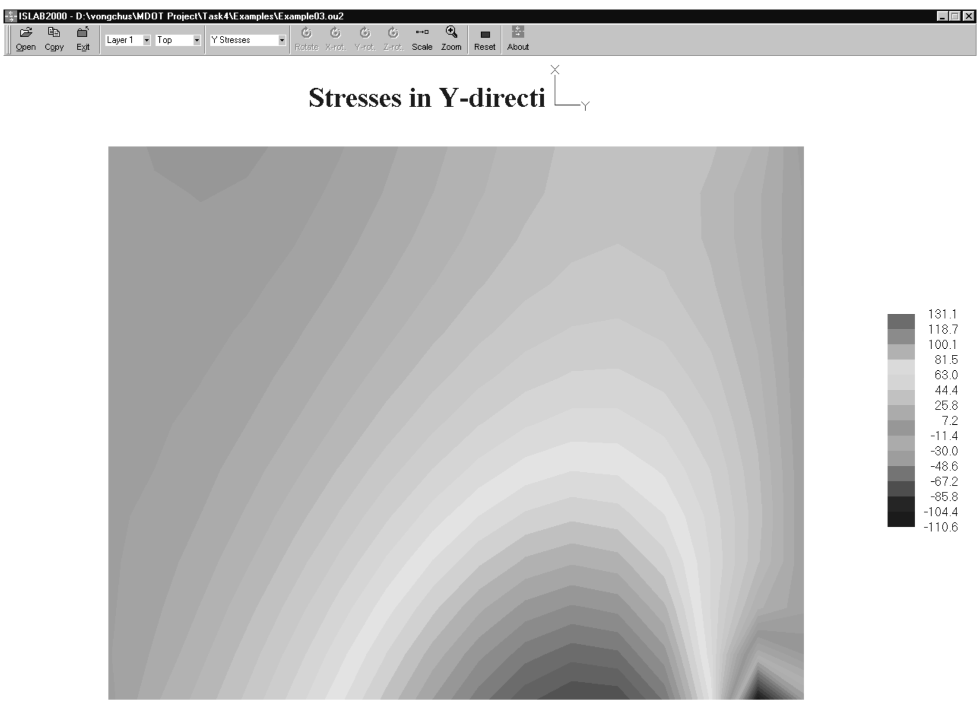


Figure E3-5: Longitudinal Stress at the Top of the PCC Slab

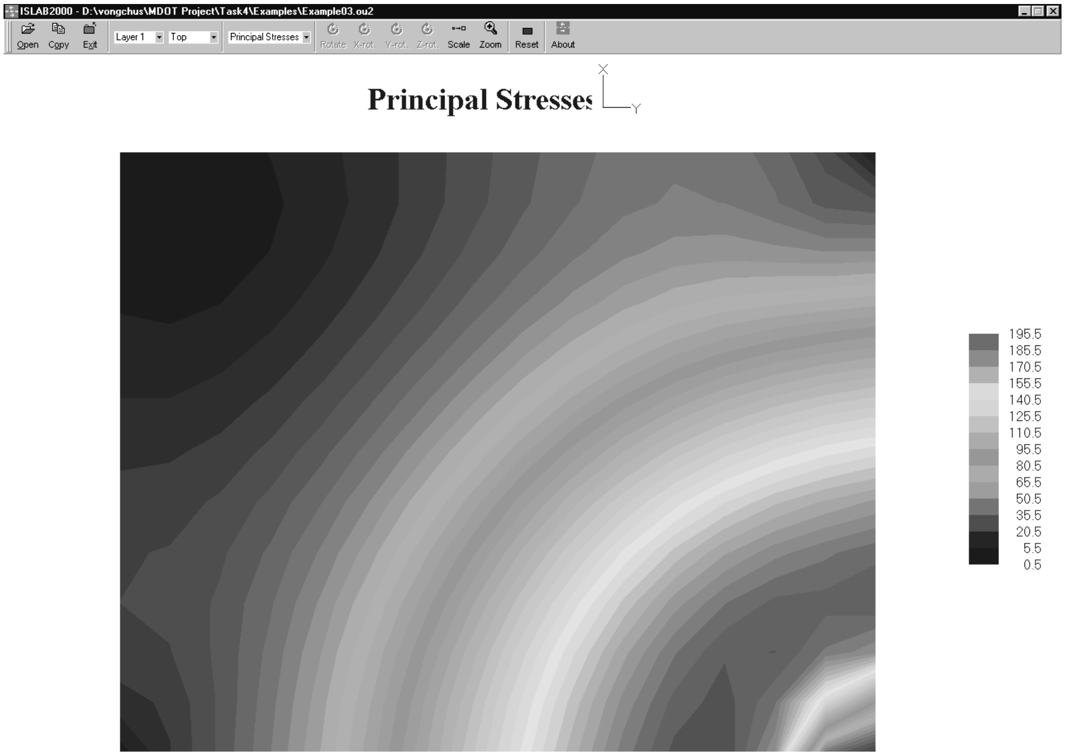


Figure E3-6: Principal Stress at the Top of the PCC Slab

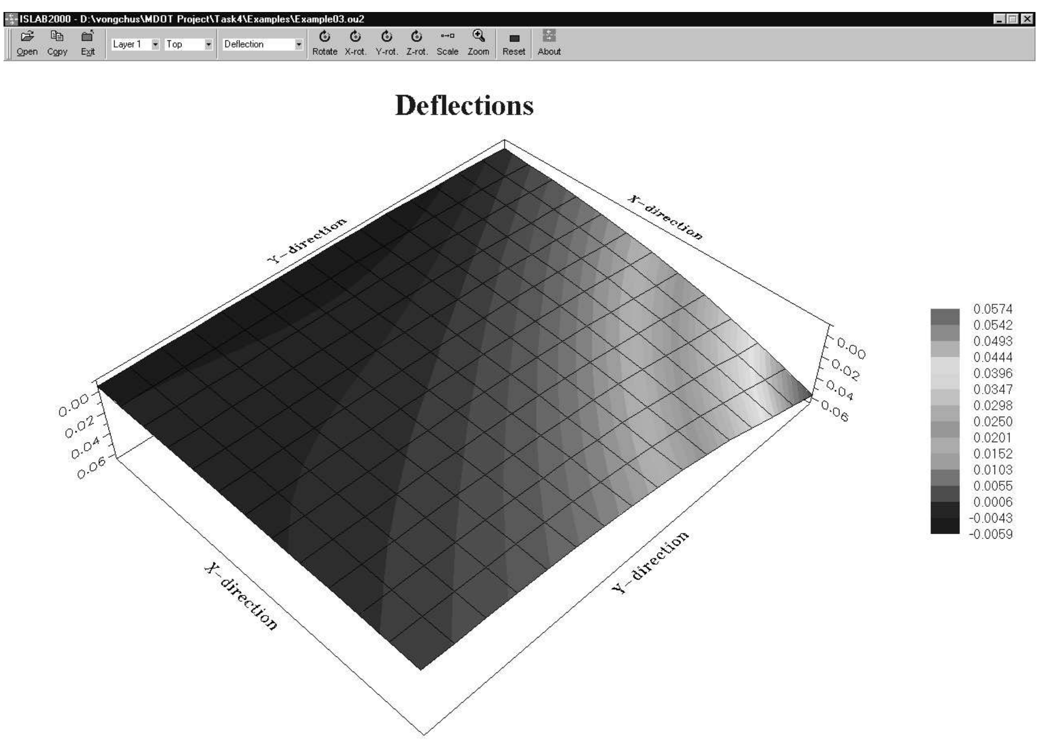


Figure E3-7: Deflection of the PCC Slab

Loading condition	Maximum stress, psi	Maximum deflection, in.
Interior	140.6	0.00796
Edge	245.5	0.02514
Corner	195.5	0.0574

Table E3-1: Comparison of results between the three loading conditions

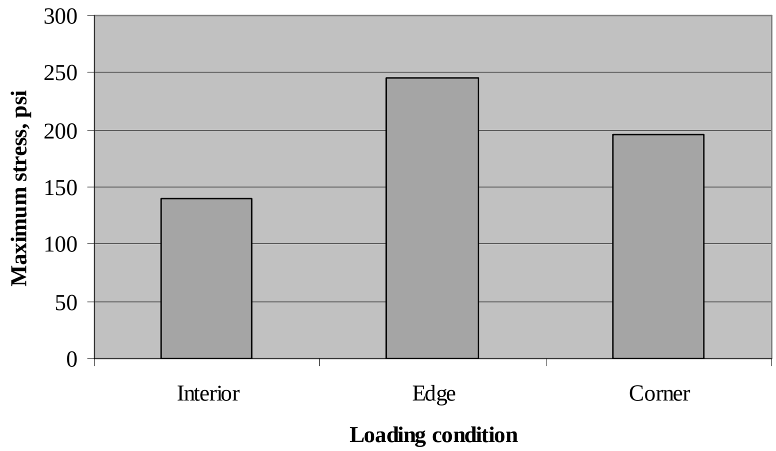


Figure E3-8: Comparison of Maximum Stress from the Three Loading Conditions

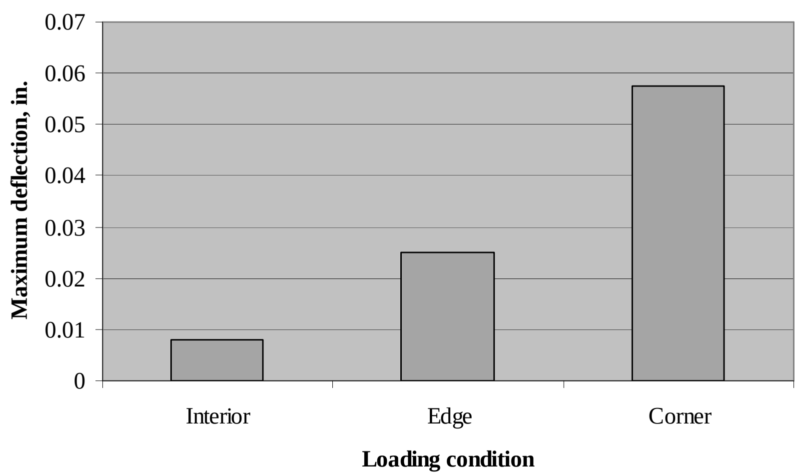


Figure E3-9: Comparison of Maximum Deflection from the Three Loading Conditions

Example 4:
Thermal Gradients on a Single Slab

Problem Statement

Determine maximum deflection and stress at the top and bottom of the PCC slab due to temperature differentials, ΔT, of -20, -10, 0, +10, +20 ^oF. Also, plot a graph to show relation between stresses and temperature differentials.

Given

Concrete elastic modulus	=	4×10^6	psi
Concrete Poisson's ratio	=	0.15	
Slab thickness	=	10	in.
Slab dimension	=	144 x 180	in^2
Mesh size	=	12 x 12	in^2 (medium)
k-value	=	100	psi/in.
Coefficient of thermal exp., α	=	4.4×10^{-6}	in./in./^oF
Temperature differential, ΔT	=	-20, -10, 0, +10, +20	^oF

Problem Illustration

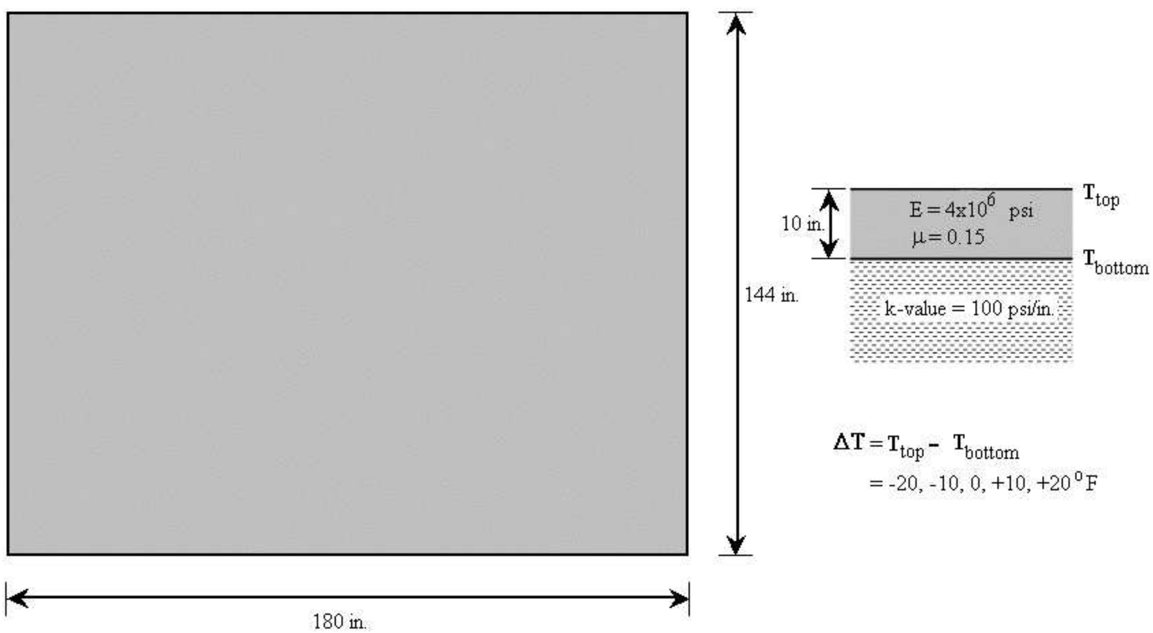


Figure E4-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 1.

Layers Module

Use this module from Example 1.

Subgrade Module

Use this module from Example 1.

Load Module

This module is not required for this example.

Temperature Module

(see Figure E4-2)

Step 1: Click **Temperature** from the main panel to open the temperature panel.

Step 2: On the temperature panel, select the **Perform Temperature Analysis** and **Batch** check boxes.

Step 3: Enter the temperature differential of the first case in the **Difference** field, (-20 ^{o}F for this problem).

Step 4: Click **Edit Batch** to open the layers temperature distributions panel.

Step 5: On the layers temperature distributions panel, click **Insert** four times to add four more cases of temperature differential. Then enter the other four temperature differentials as identified in the problem statement.

Step 6: Click **OK** to close the layers temperature distributions panel.

Step 7: Click **OK** layers temperature properties panel.

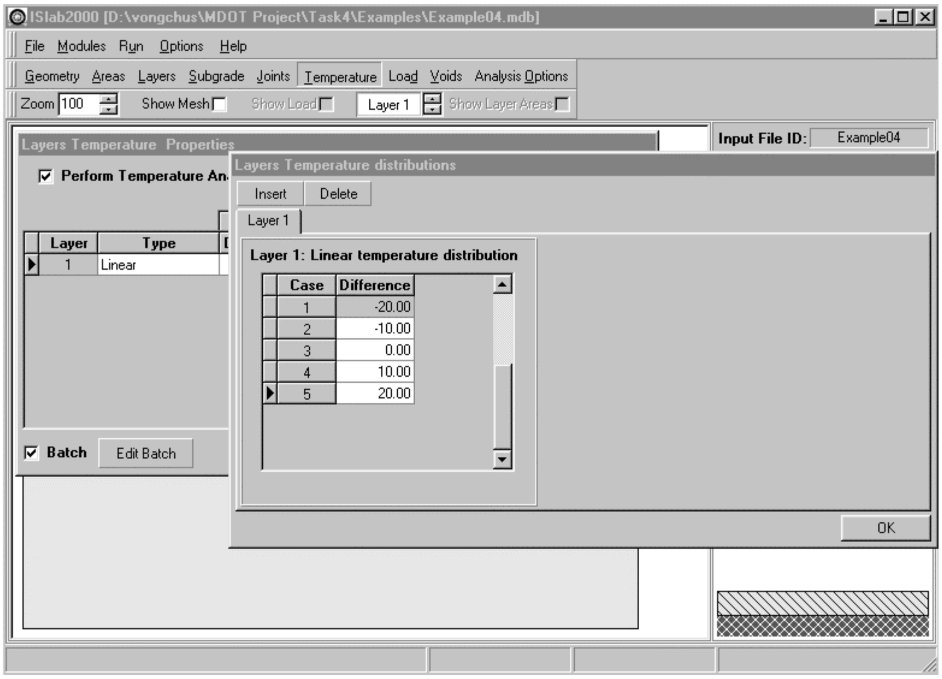


Figure E4-2: Edit Inputs for the Temperature Module

Analysis Options Module

(see Figure E4-3)

Click **Analysis Options** to open the analysis options panel, and then select the **Batch Processing** checkbox. Click **OK** to close the analysis options panel.

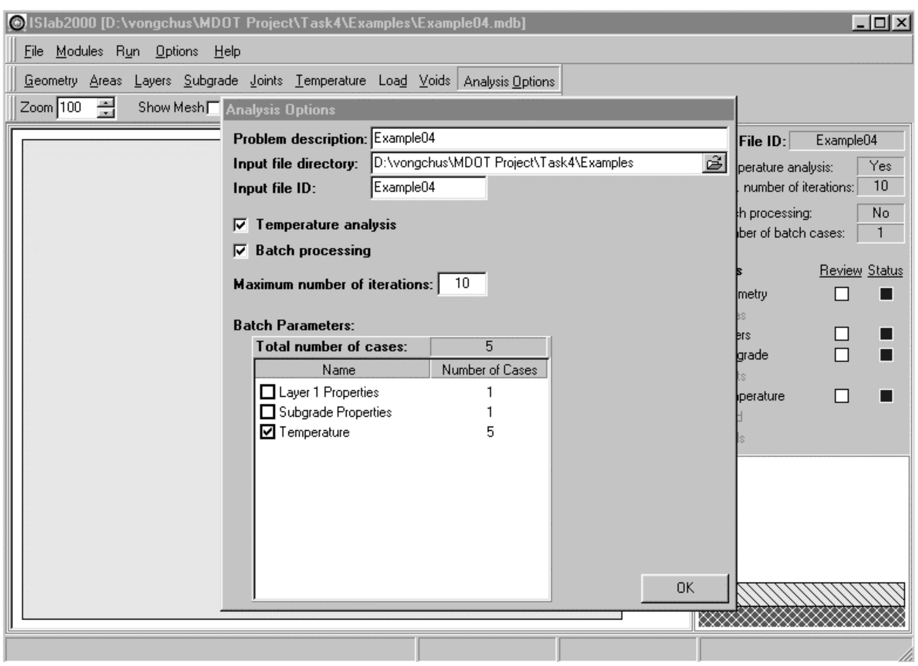


Figure E4-3: Analysis Option Module

The main panel displays the pavement structure, loading condition, and meshing as shown in Figure E4-4.

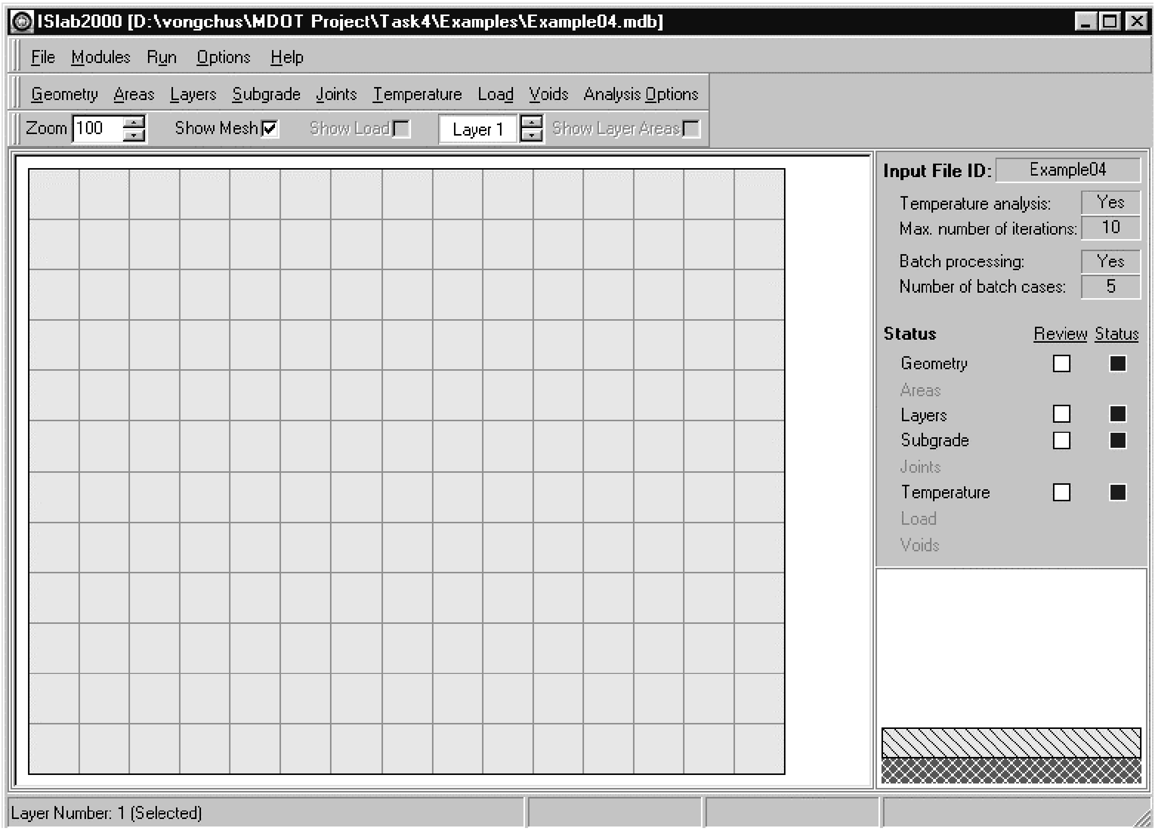


Figure E4-4: Main Panel After the Completion of Inputs

Analysis Results

Table E4-1 summarizes the analysis results for all five temperature differentials. Stress and deflection contours from ISLAB2000 are also available in Figures E4-5 through E4-14. Figure E4-15 is the plot of relationship between stresses and temperature differentials.

ΔT, ^{o}F	Stress at the bottom of the PCC, psi		Stress at the top of the PCC, psi		Deflection, in.
	Transverse	Longitudinal	Transverse	Longitudinal	
-20	-47.4	-79.1	47.4	79.1	0.02163
-10	-27.2	-45.9	27.2	45.9	0.01532
0	0.0	0.0	0.0	0.0	0.00870
10	27.6	46.5	-27.6	-46.5	0.02306
20	46.5	83.6	-46.5	-83.6	0.03739

Table E4-1: Analysis Results

NOTE
Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

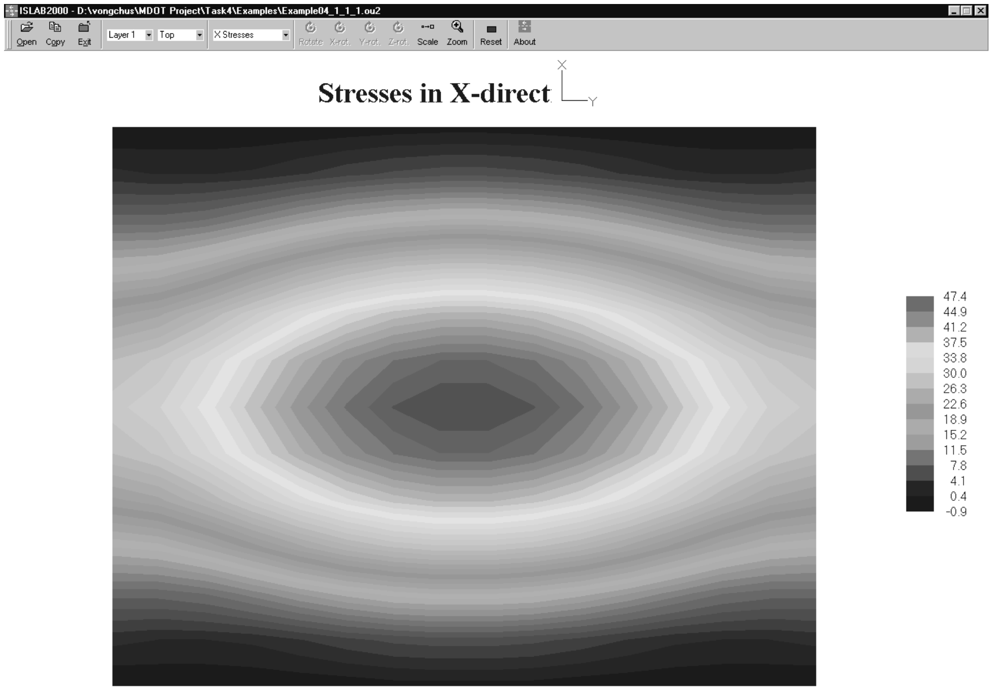


Figure E4-5: Transverse Stress at the Top of the PCC Slab, ΔT = -20 °F

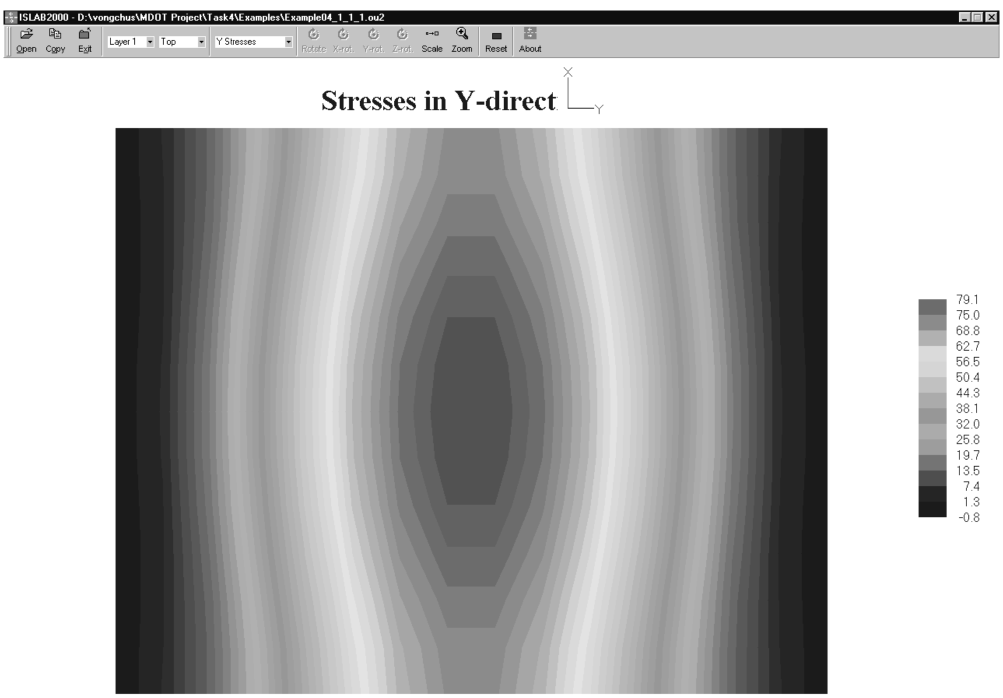


Figure E4-6: Longitudinal Stress at the Top of the PCC Slab, ΔT = -20 °F

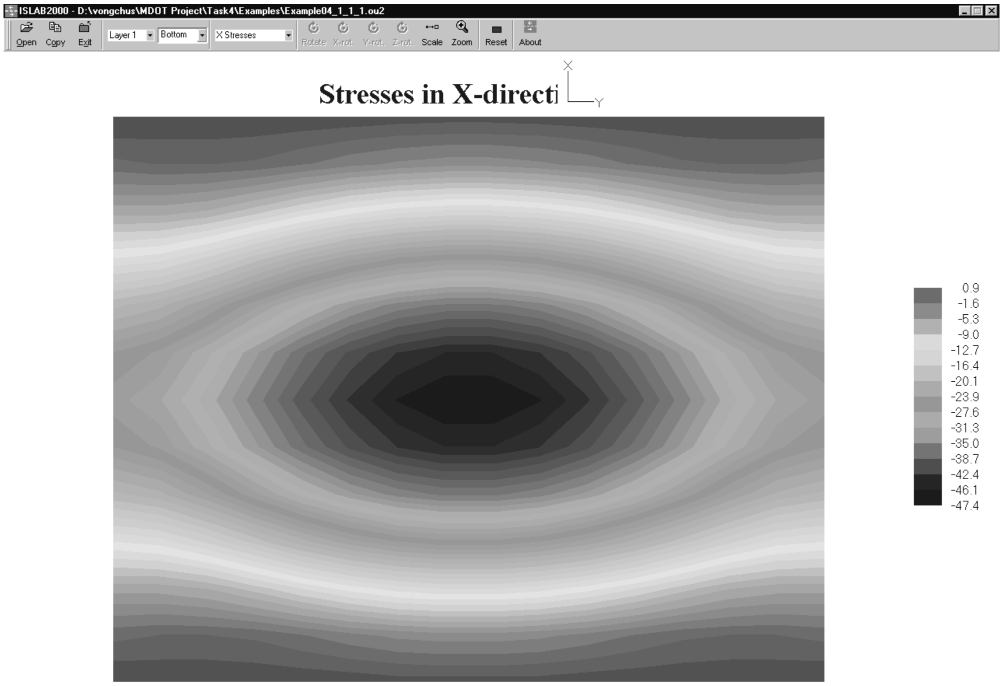


Figure E4-7: Transverse Stress at the Bottom of the PCC Slab, ΔT = -20 °F

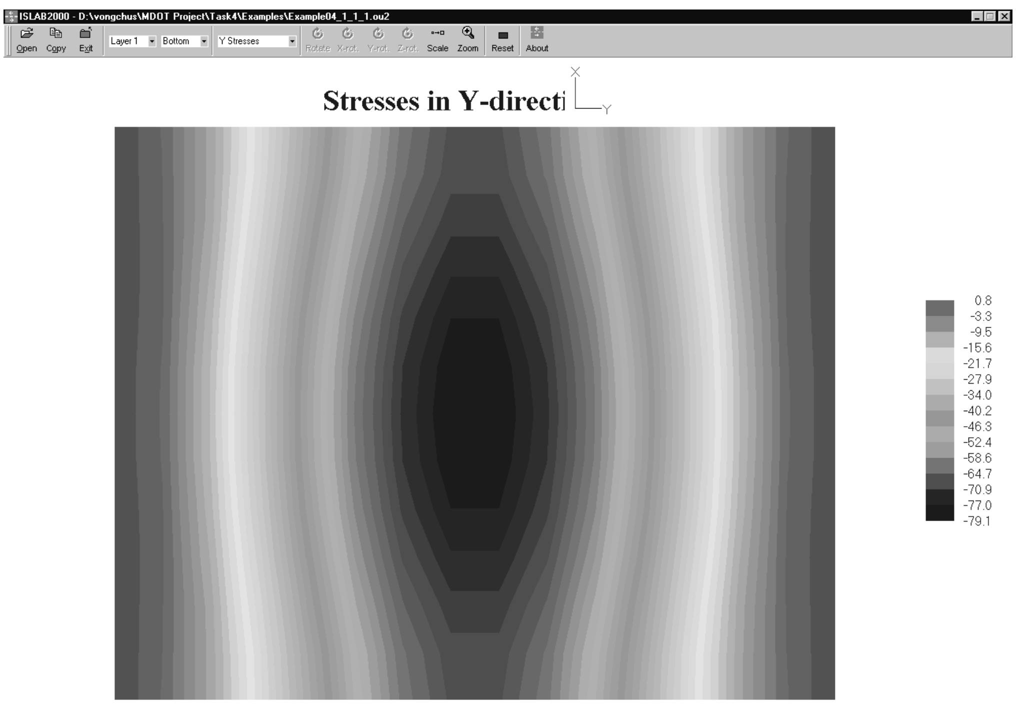


Figure E4-8: Longitudinal Stress at the Bottom of the PCC Slab, ΔT = -20 °F

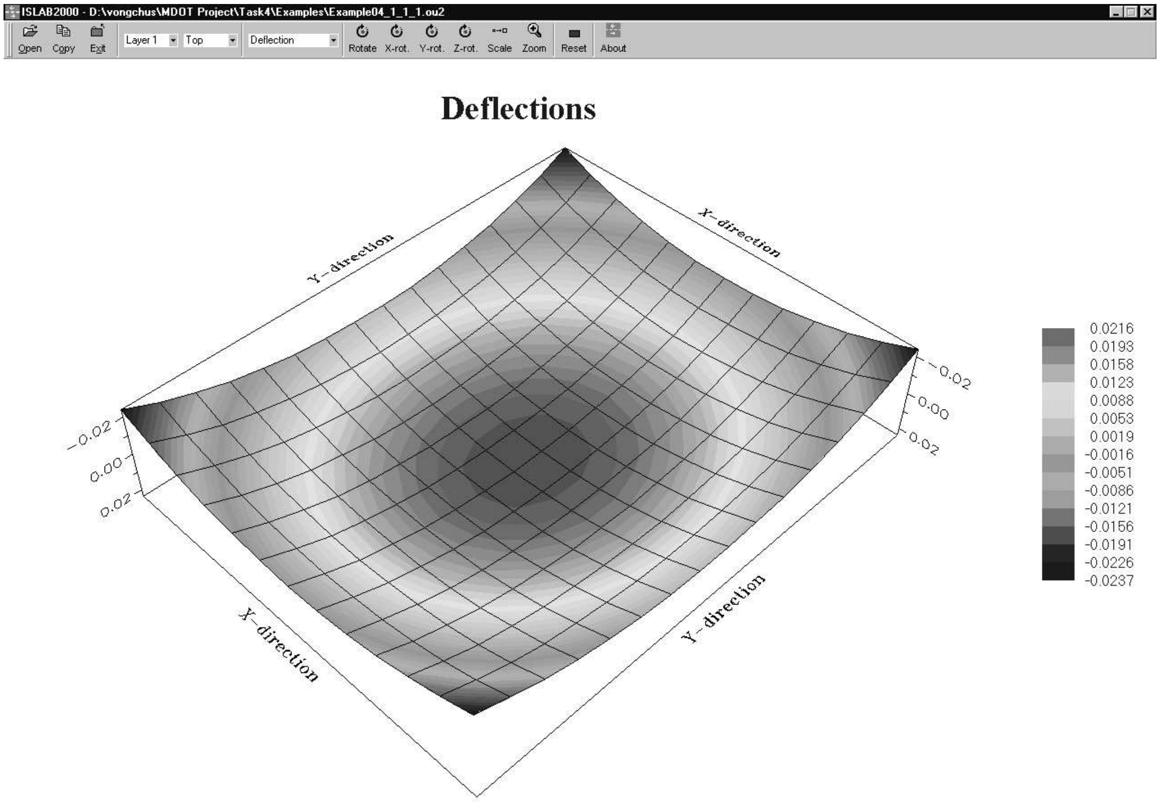


Figure E4-9: Deflection of the PCC slab, ΔT = -20 °F

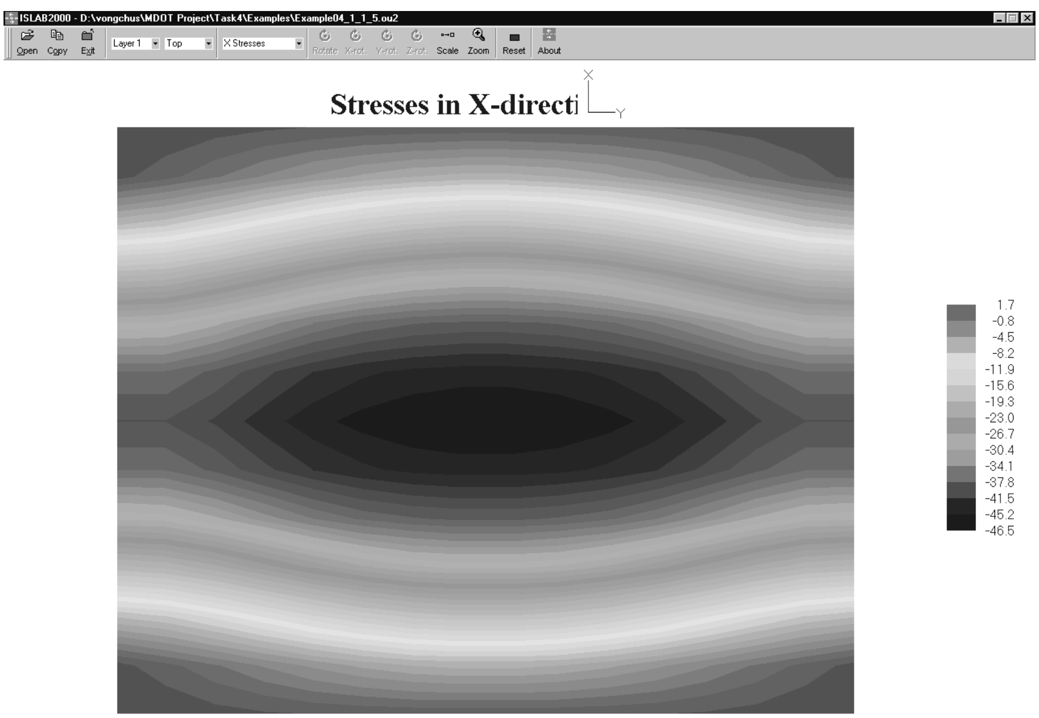


Figure E4-10: Transverse stress at the top of the PCC slab, ΔT = +20 °F

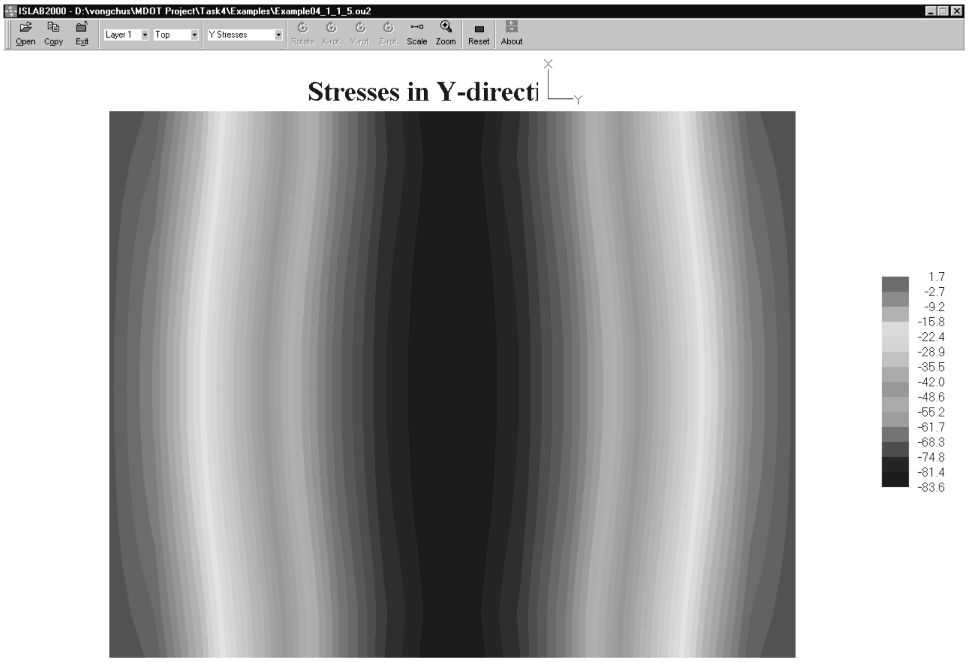


Figure E4-11: Longitudinal stress at the top of the PCC slab, ΔT = +20 °F

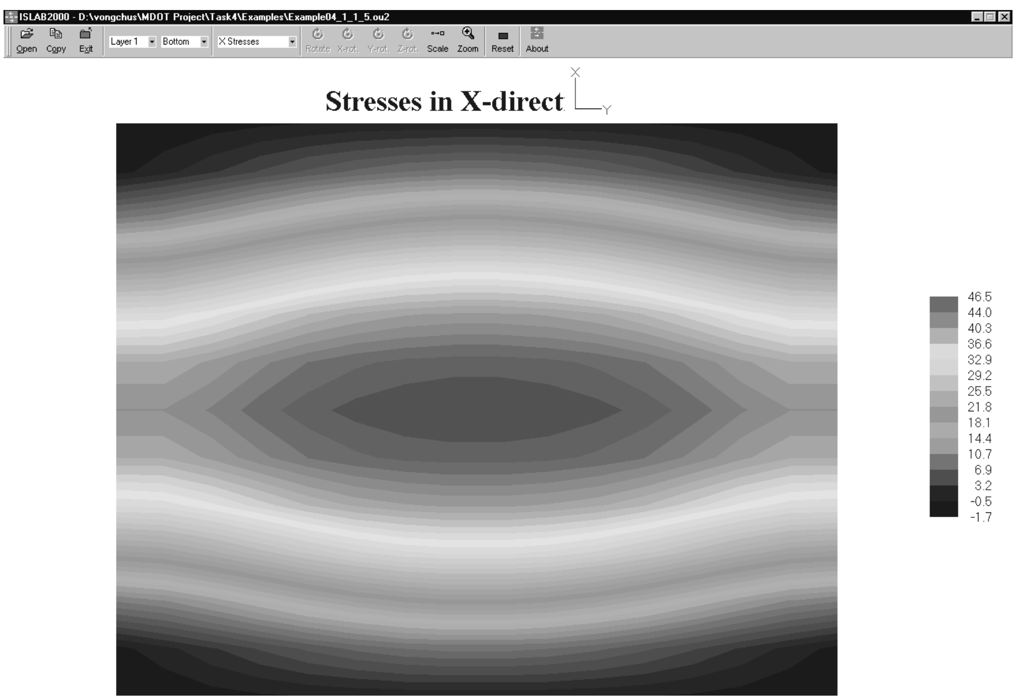


Figure E4-12: Transverse stress at the bottom of the PCC slab, ΔT = +20 °F

Figure E4-13: Longitudinal Stress at the Bottom of the PCC Slab, ∆T = +20 °F

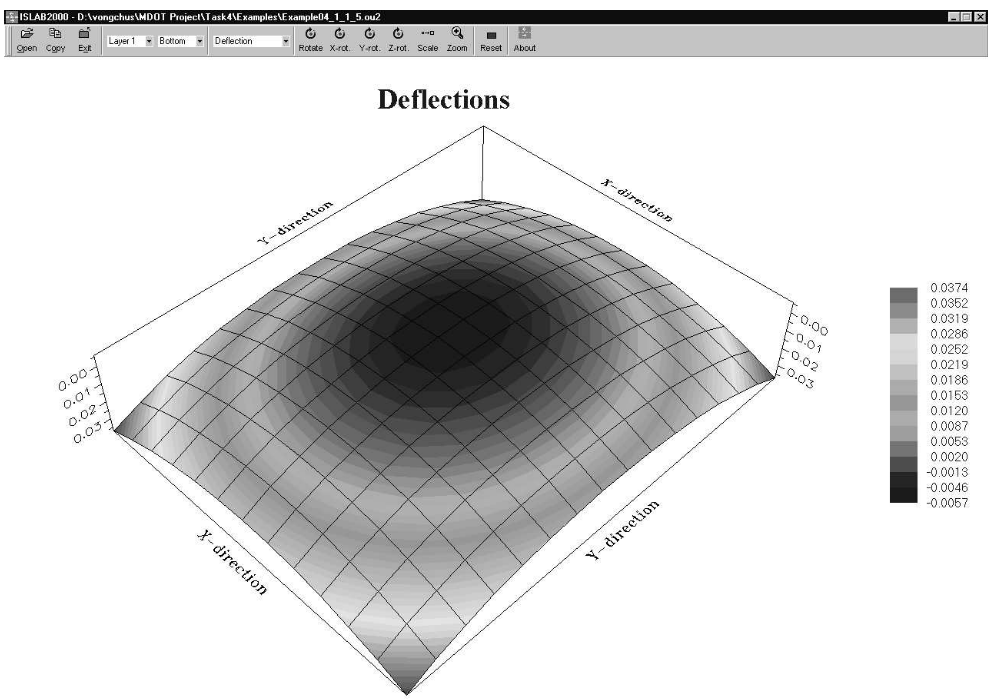


Figure E4-14: Deflection of the PCC Slab, ∆T = +20 °F

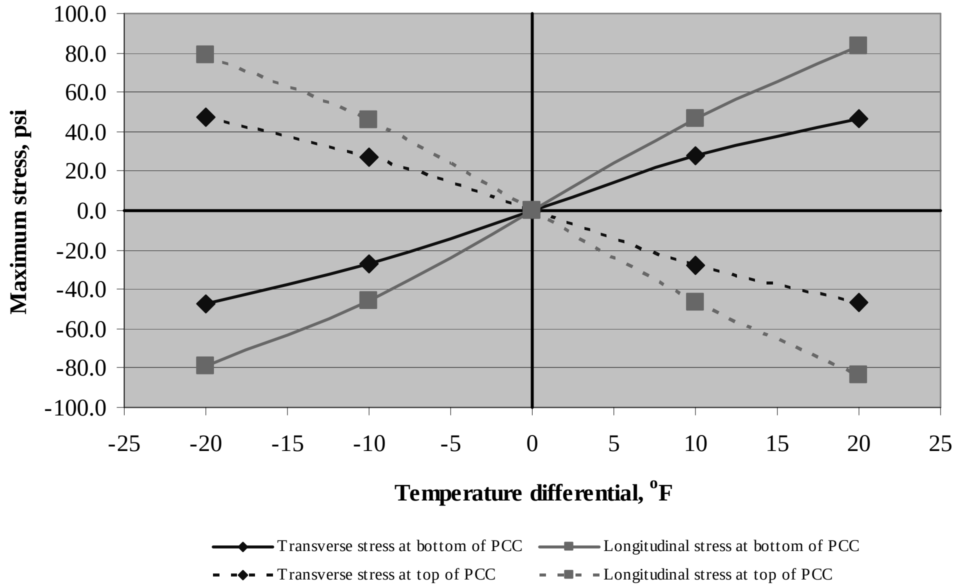


Figure E4-15: Relationship Between Stresses and Temperature Differentials

Example 5:
Interior Loading with Thermal Gradients on a Single Slab

Problem Statement

Determine maximum deflection and stress at the bottom of the PCC slab for Westergaard's interior loading condition with temperature differentials, ΔT, of -20, -10, 0, +10, +20 ^oF.

Given

Concrete elastic modulus	=	4×10^6	psi
Concrete Poisson's ratio	=	0.15	
Slab thickness	=	10	in.
Slab dimension	=	144 x 180	in^2
Mesh size	=	12 x 12	in^2 (medium)
k-value	=	100	psi/in.
Tire contact area	=	7.5x15	in^2
Wheel load	=	10,000	lbs
Coefficient of thermal exp., α	=	4.4×10^{-6}	in./in./^oF
Temperature differential, ΔT	=	-20, -10, 0, +10, +20	^oF

Problem Illustration

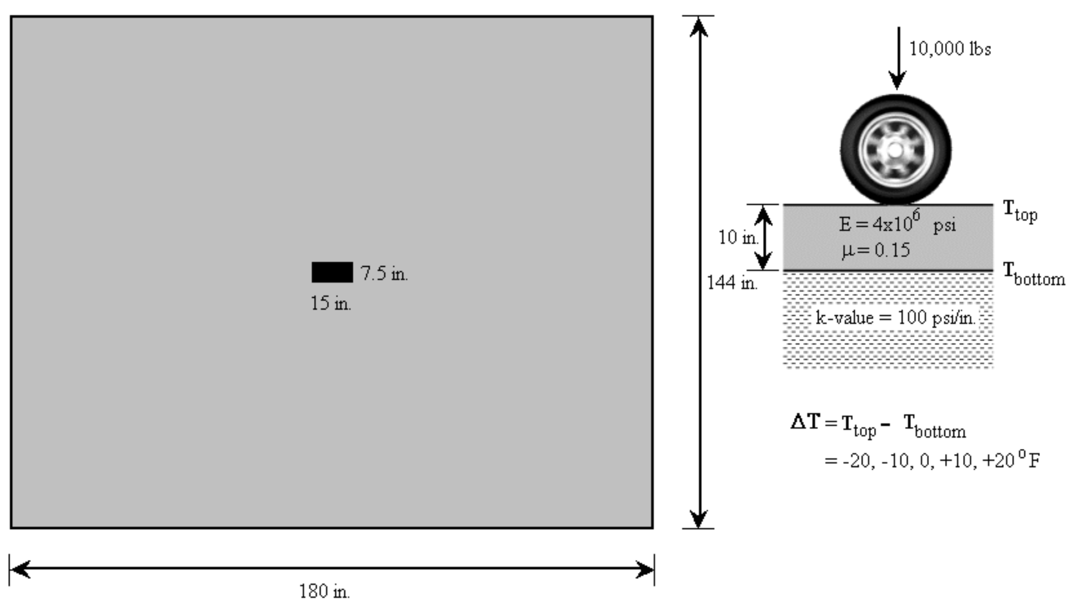


Figure E5-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 1.

Layers Module

Use this module from Example 1.

Subgrade Module

Use this module from Example 1.

Load Module

Use this module from Example 1.

Temperature Module

Use this module from Example 4.

Analysis options Module

Use this module from Example 4.

The main panel should display the pavement structure, loading condition, and meshing as shown in Example 1 (Figure E1-7.)

Analysis Results

Table E5-1 summarizes the analysis results for all five temperature differentials. Stress and deflection contours from ISLAB2000 are also available in Figures E5-2 through E5-7. Figures E5-8 and E5-9 are the plots of relationship between stresses and temperature differentials and between deflections and temperature differentials, respectively.

ΔT, ^oF	Stress at the bottom of the PCC, psi		Deflection, in.
	Transverse	Longitudinal	
-20	91.7	41.1	0.02971
-10	113.5	77.5	0.01650
0	140.6	123.4	0.01480
10	168.2	169.8	0.01043
20	195.8	216.3	0.00607

Table E5-1: Analysis Results

NOTE

Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

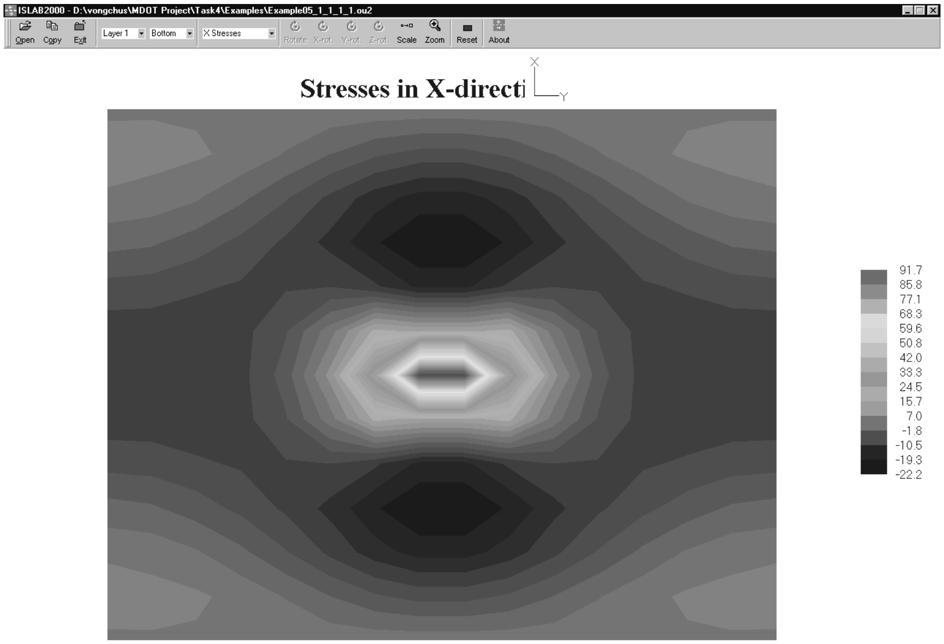


Figure E5-2: Transverse Stress at the Bottom of the PCC Slab, ΔT = -20 °F

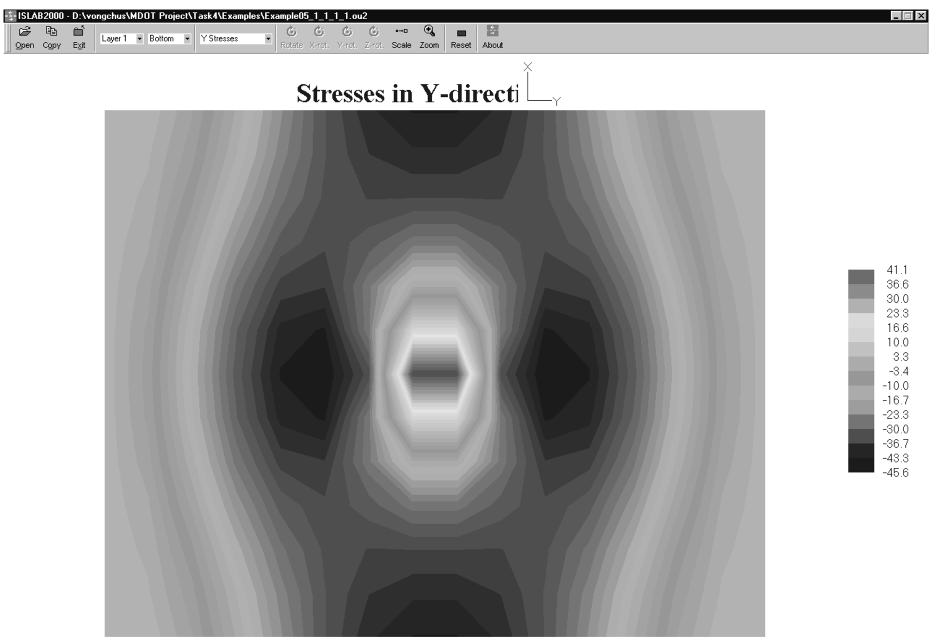


Figure E5-3: Longitudinal Stress at the Bottom of the PCC Slab, ΔT = -20 °F

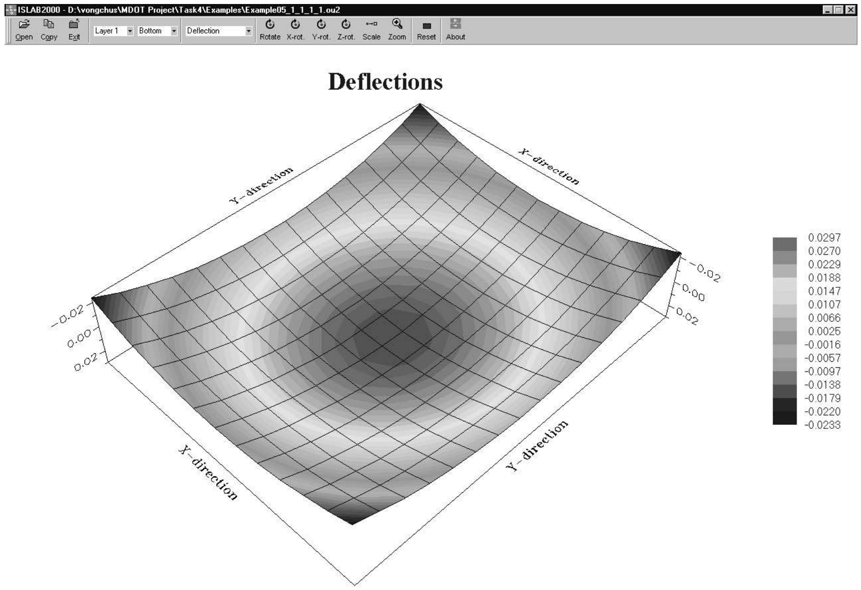


Figure E5-4: Deflection of the PCC Slab, ΔT = -20 °F

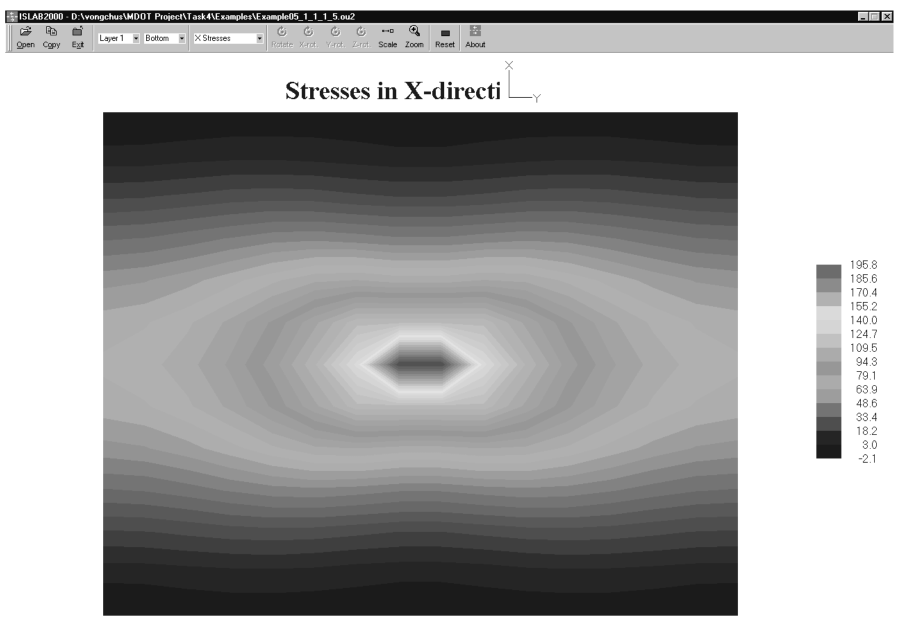


Figure E5-5: Transverse Stress at the Bottom of the PCC Slab, ΔT = +20 °F

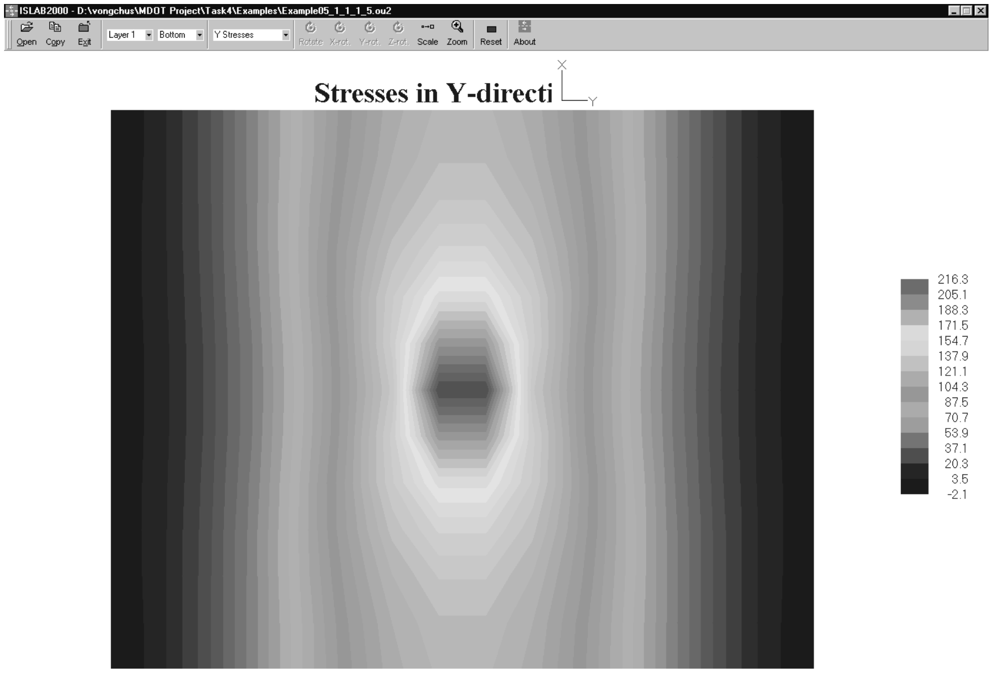


Figure E5-6: Longitudinal Stress at the Bottom of the PCC Slab, ΔT = +20 °F

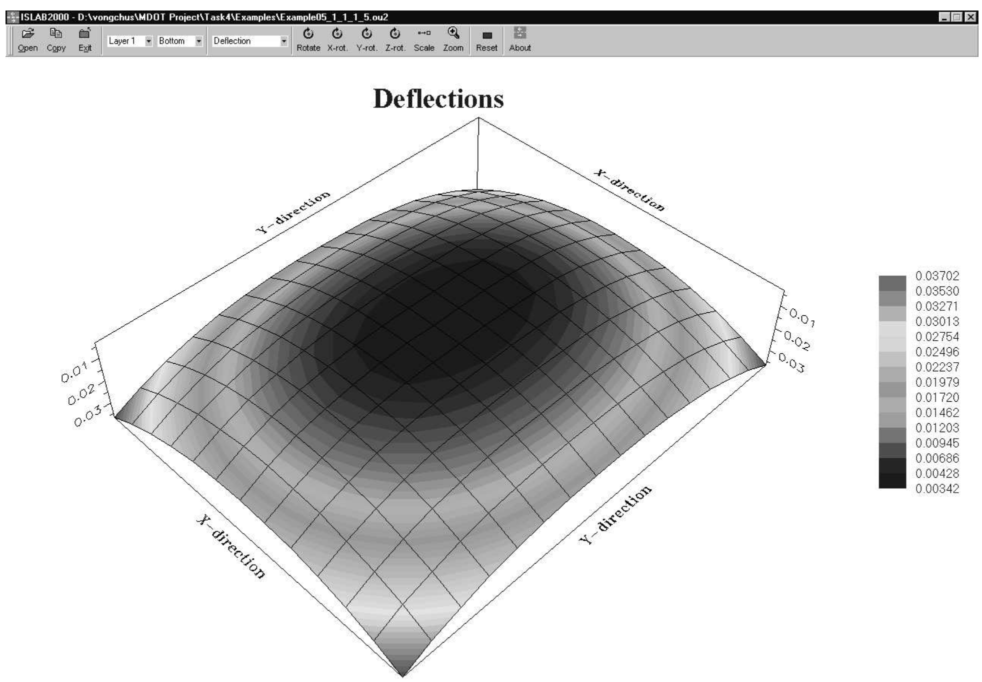
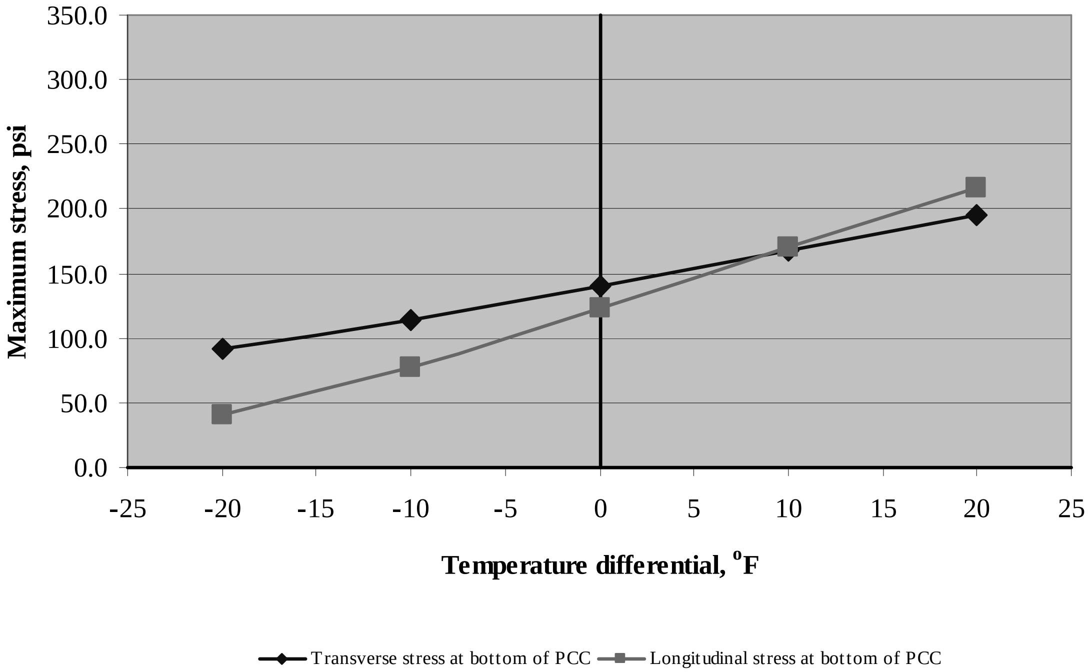
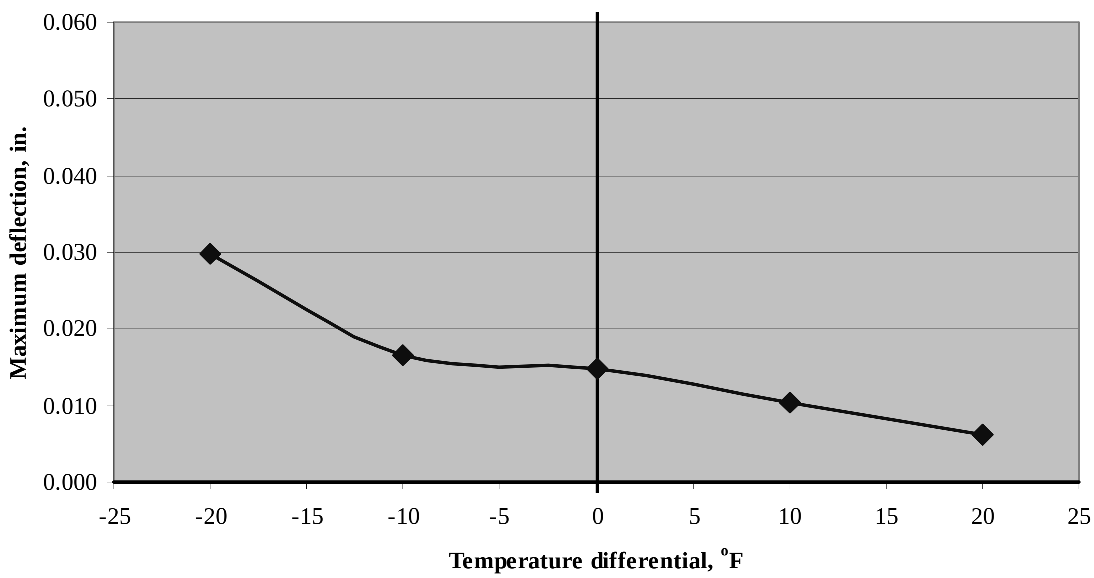


Figure E5-7: Deflection of the PCC Slab, ΔT = +20 °F



E5-8: Relationship Between Stresses and Temperature Differentials



E5-9: Relationship Between Deflections and Temperature Differentials

Example 6:
Edge Loading with Thermal Gradients on a Single Slab

Problem Statement

Determine maximum deflection and stress at the bottom of the PCC slab for Westergaard's edge loading condition with temperature differentials, ΔT, of -20, -10, 0, +10, +20 ^oF.

Given

Concrete elastic modulus	=	4×10^6	psi
Concrete Poisson's ratio	=	0.15	
Slab thickness	=	10	in.
Slab dimension	=	144 x 180	in^2
Mesh size	=	12 x 12	in^2 (medium)
k-value	=	100	psi/in.
Tire contact area	=	7.5 x 15	in^2
Wheel load	=	10,000	lbs
Coefficient of thermal exp., α	=	4.4×10^{-6}	in./in./^oF
Temperature differential, ΔT	=	-20, -10, 0, +10, +20	^oF

Problem Illustration

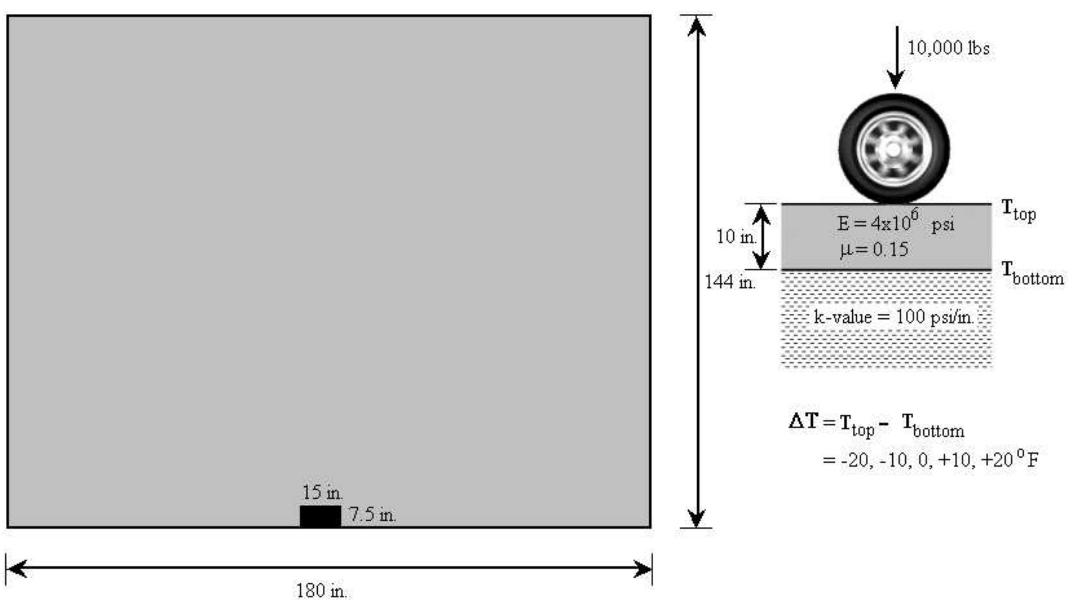


Figure E6-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 1.

Layers Module

Use this module from Example 1.

Subgrade Module

Use this module from Example 1.

Load Module

Use this module from Example 1.

Temperature Module

Use this module from Example 4.

Analysis Options Module

Use this module from Example 4.

The main panel should display the pavement structure, loading condition, and meshing as shown in Example 2 (Figure E2-3.)

Analysis Results

Table E6-1 summarizes the analysis results for all five temperature differentials. Stress and deflection contours from ISLAB2000 are also available in Figures E6-2 through E6-7. Figures E6-8 and E6-9 are the plots of relationship between stresses and temperature differentials and between deflections and temperature differentials, respectively.

ΔT, ^oF	Stress at the bottom of the PCC, psi		Deflection, in.
	Transverse	Longitudinal	
-20	37.4	165.4	0.03000
-10	37.4	203.1	0.03130
0	37.4	245.5	0.03384
10	37.3	289.1	0.03685
20	37.3	332.1	0.03982

Table E6-1: Analysis results

NOTE
Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

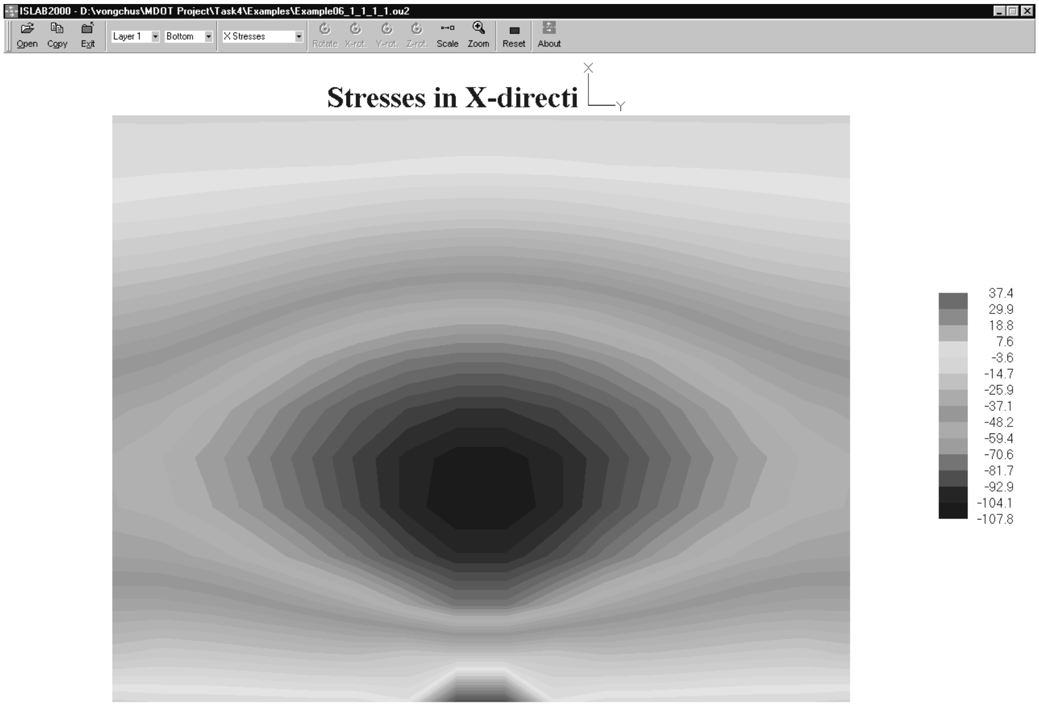


Figure E6-2: Transverse Stress at the Bottom of the PCC Slab, ΔT = -20 °F

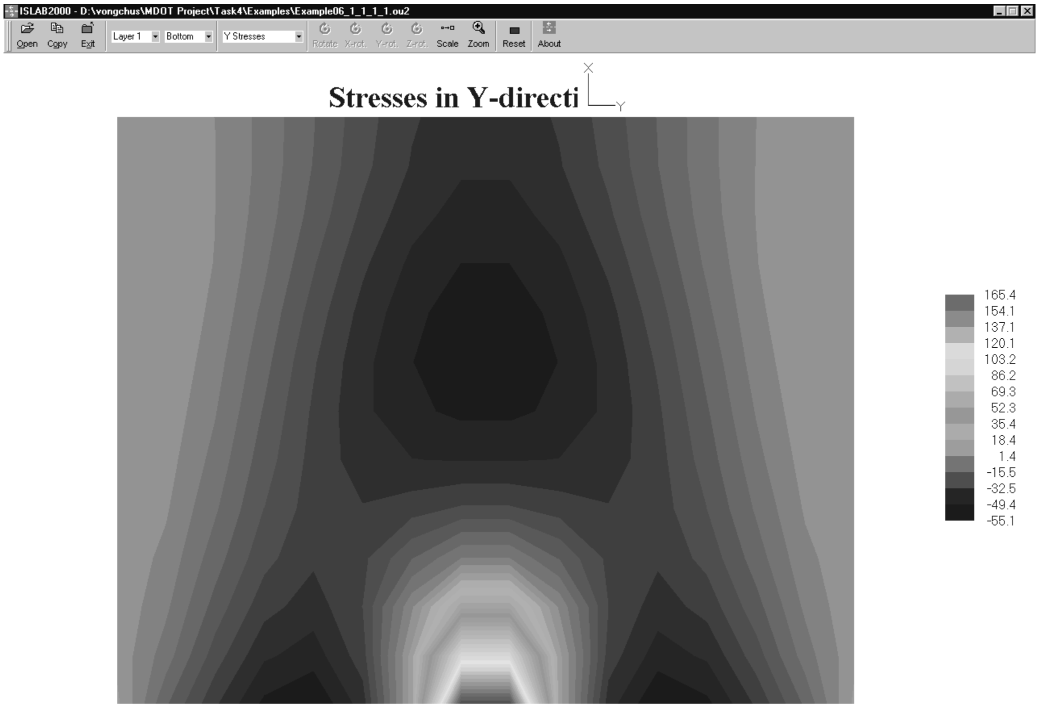


Figure E6-3: Longitudinal Stress at the Bottom of the PCC Slab, ΔT = -20 °F

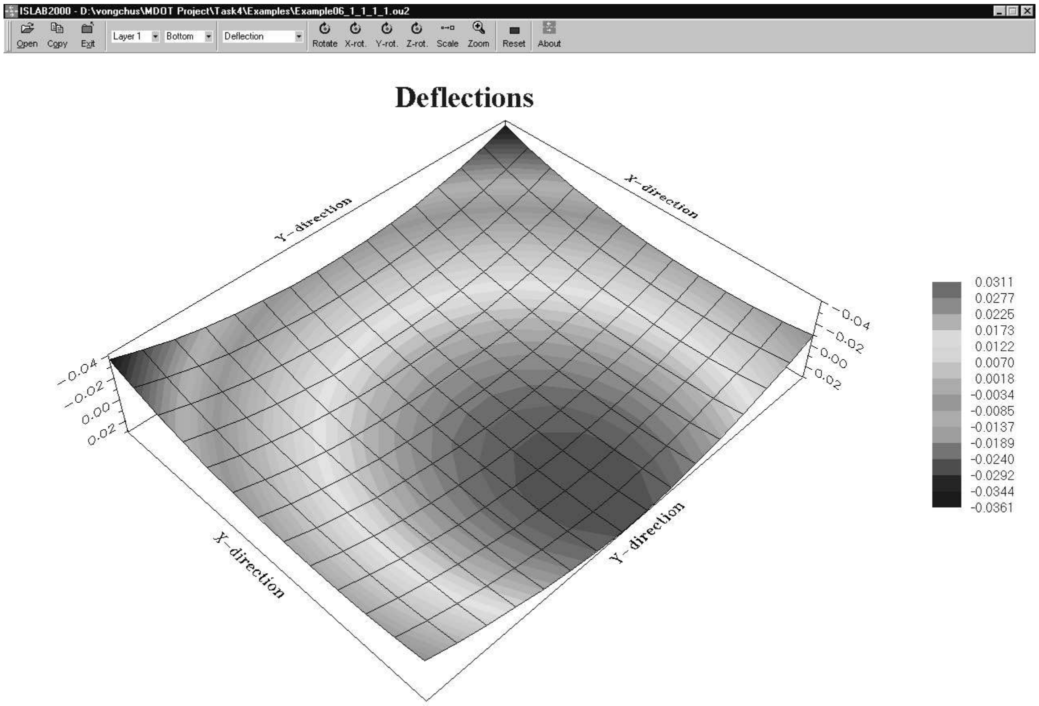


Figure E6-4: Deflection of the PCC slab, ΔT = -20 °F

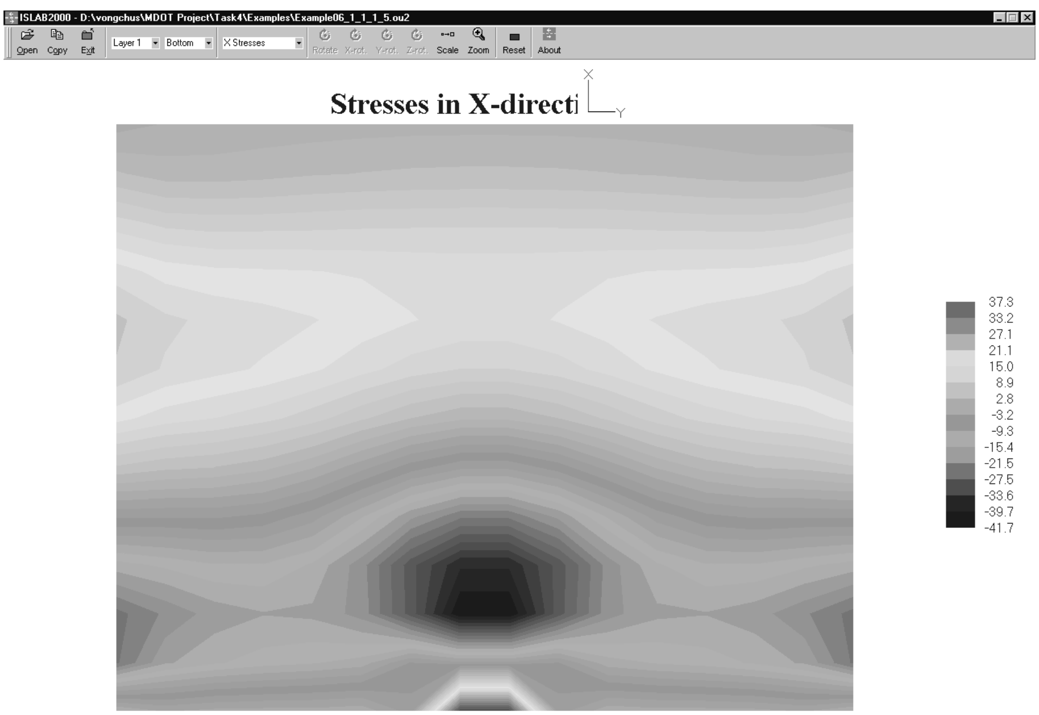


Figure E6-5: Transverse Stress at the Bottom of the PCC Slab, ΔT = +20 °F

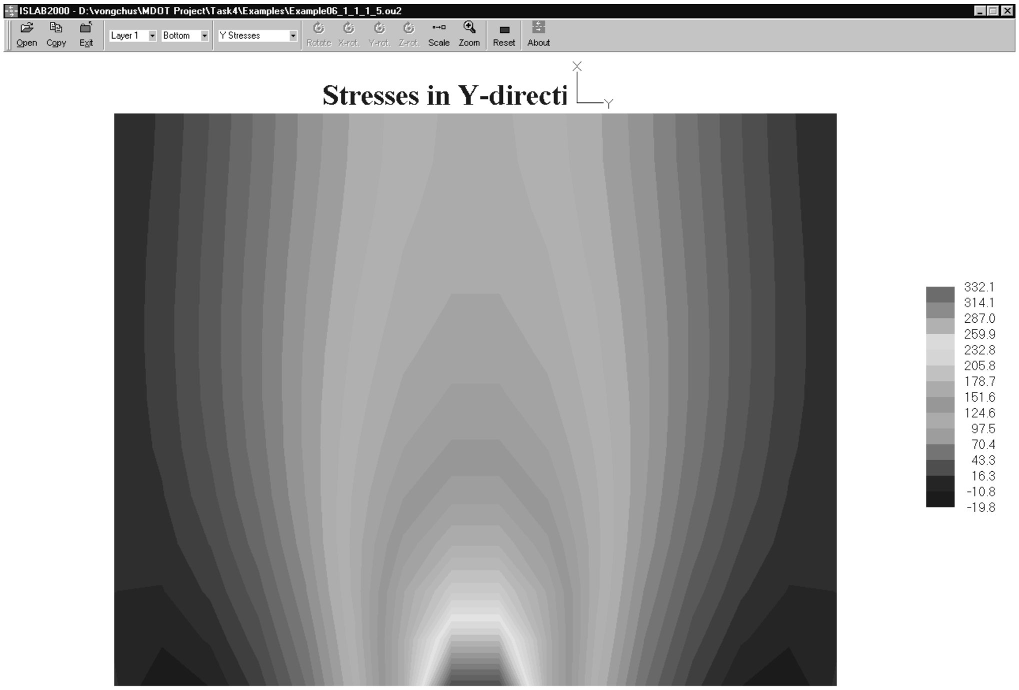


Figure E6-6: Longitudinal Stress at the Bottom of the PCC Slab, ΔT = +20 °F

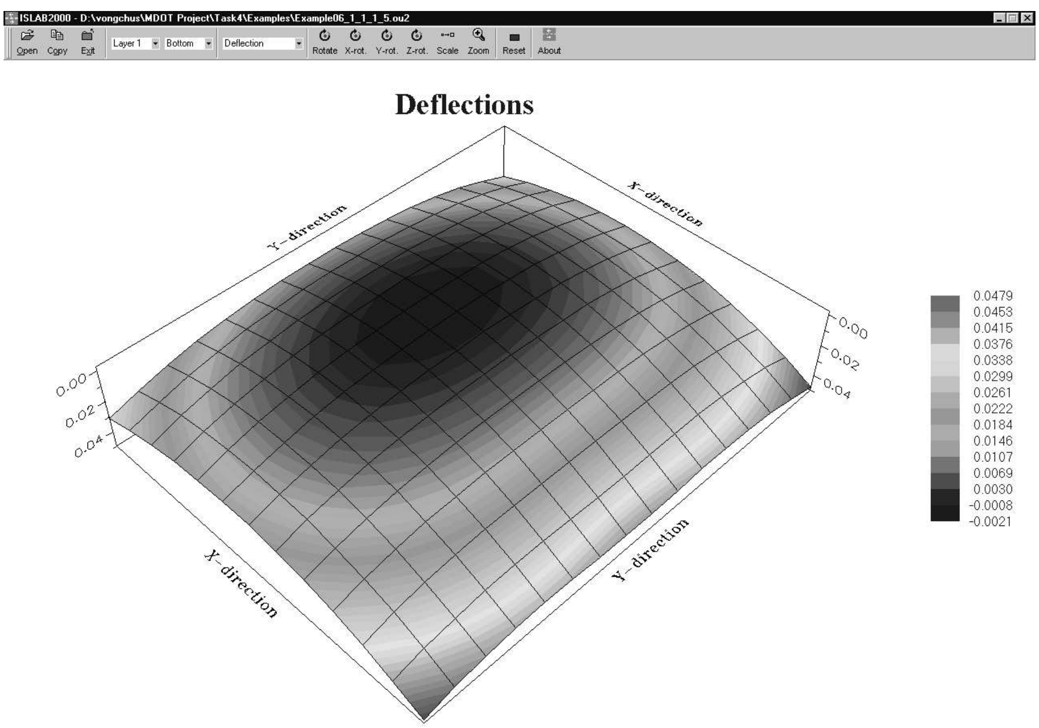
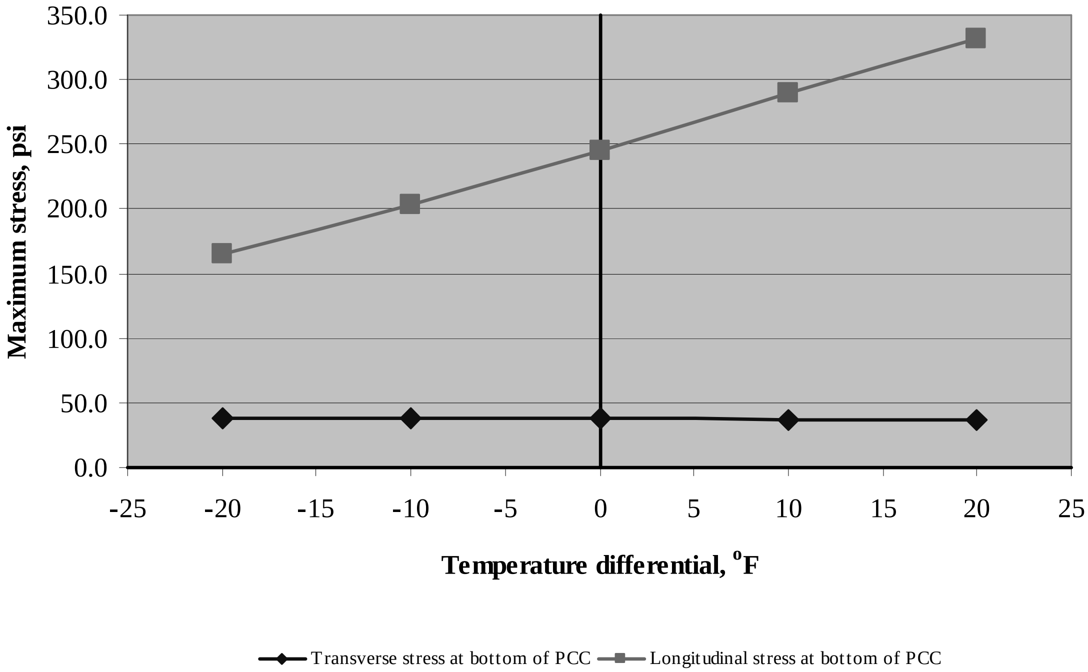
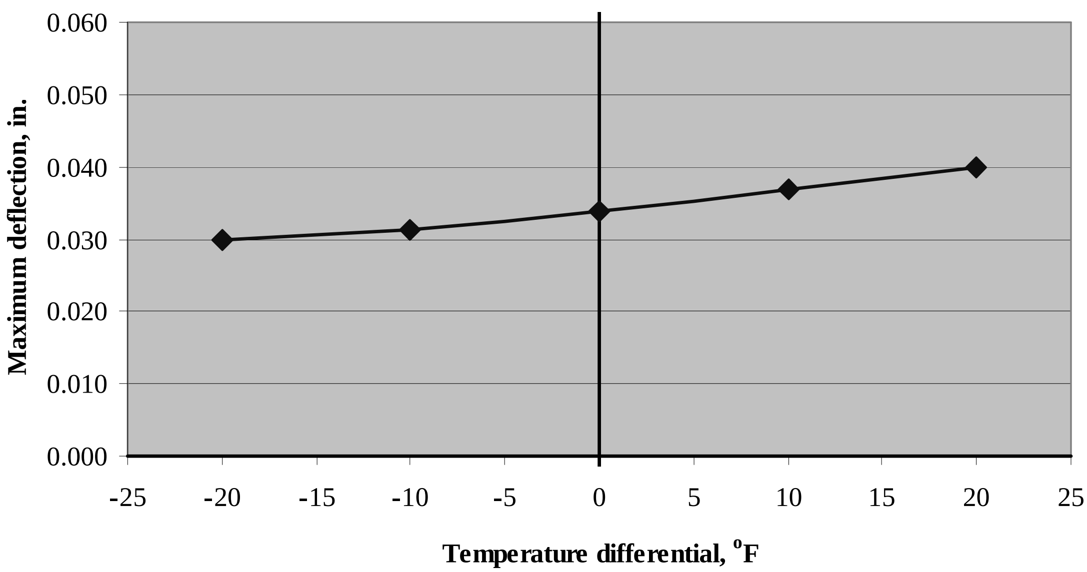


Figure E6-7: Deflection of the PCC Slab, ΔT = +20 °F



E6-8: Relationship Between Stresses and Temperature Differentials



E6-9: Relationship Between Deflections and Temperature Differentials

Example 7:
Corner Loading with Thermal Gradients on a Single Slab

Problem Statement

Determine maximum deflection and stress at the top of the PCC slab for Westergaard's corner loading condition with temperature differentials, ΔT, of -20, -10, 0, +10, +20 ^oF.

Given

Concrete elastic modulus	=	4×10^6	psi
Concrete Poisson's ratio	=	0.15	
Slab thickness	=	10	in.
Slab dimension	=	144x180	in^2
Mesh size	=	12x12	in^2 (medium)
k-value	=	100	psi/in.
Tire contact area	=	7.5x15	in^2
Wheel load	=	10,000	lbs
Coefficient of thermal exp., α	=	4.4×10^{-6}	in./in./^oF
Temperature differential, ΔT	=	-20, -10, 0, +10, +20	^oF

Problem Illustration

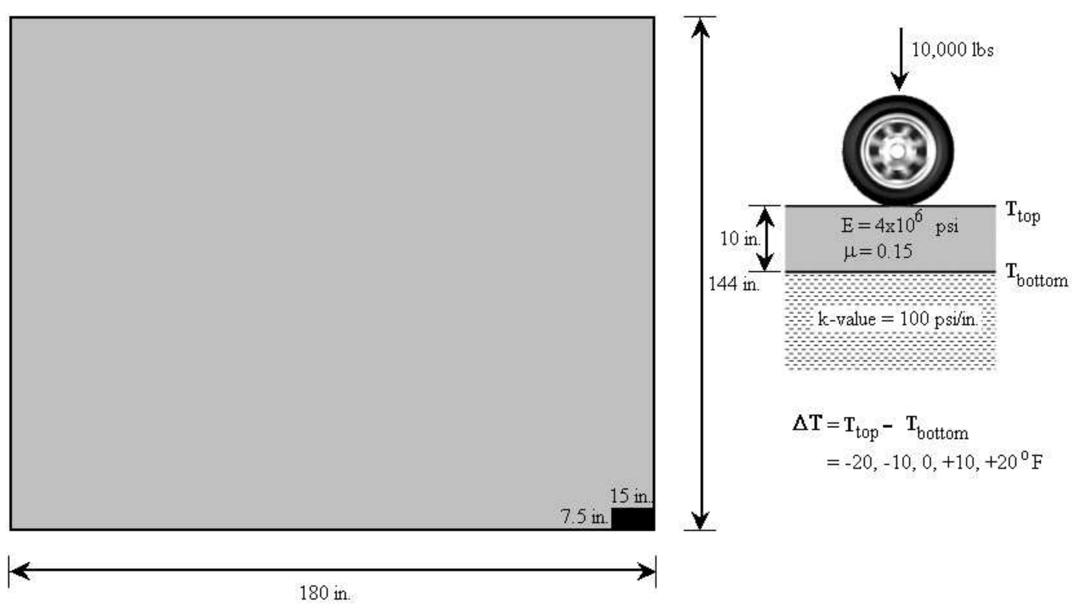


Figure E7-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 1.

Layers Module

Use this module from Example 1.

Subgrade Module

Use this module from Example 1.

Load Module

Use this module from Example 1.

Temperature Module

Use this module from Example 4.

Analysis Options Module

Use this module from Example 4.

The main panel should display the pavement structure, loading condition, and meshing as shown in Example 2 (Figure E2-3.)

Analysis Results

Table E7-1 summarizes the analysis results for all five temperature differentials. Stress and deflection contours from ISLAB2000 are also available in Figures E7-2 through E7-5. Figures E7-6 and E7-7 are the plots of relationship between stresses and temperature differentials and between deflections and temperature differentials, respectively.

ΔT, ^oF	Corner stress, psi	Deflection, in.
-20	232.0	0.03923
-10	213.5	0.05201
0	195.5	0.06614
10	182.5	0.08050
20	174.3	0.09524

Table E7-1: Analysis Results

NOTE
Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

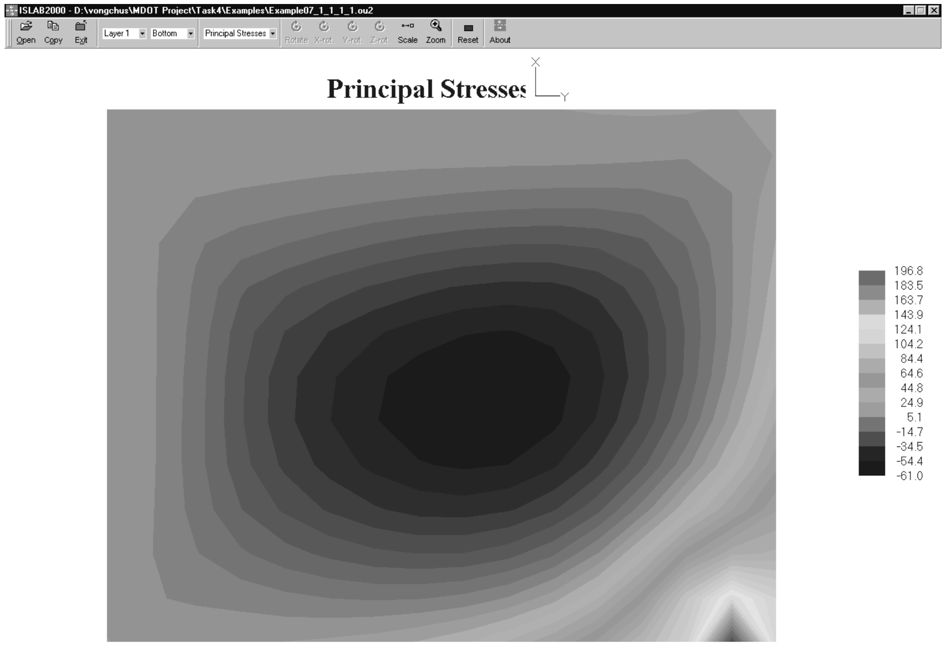


Figure E7-2: Corner Stress at the Top of the PCC Slab, ΔT = -20 °F

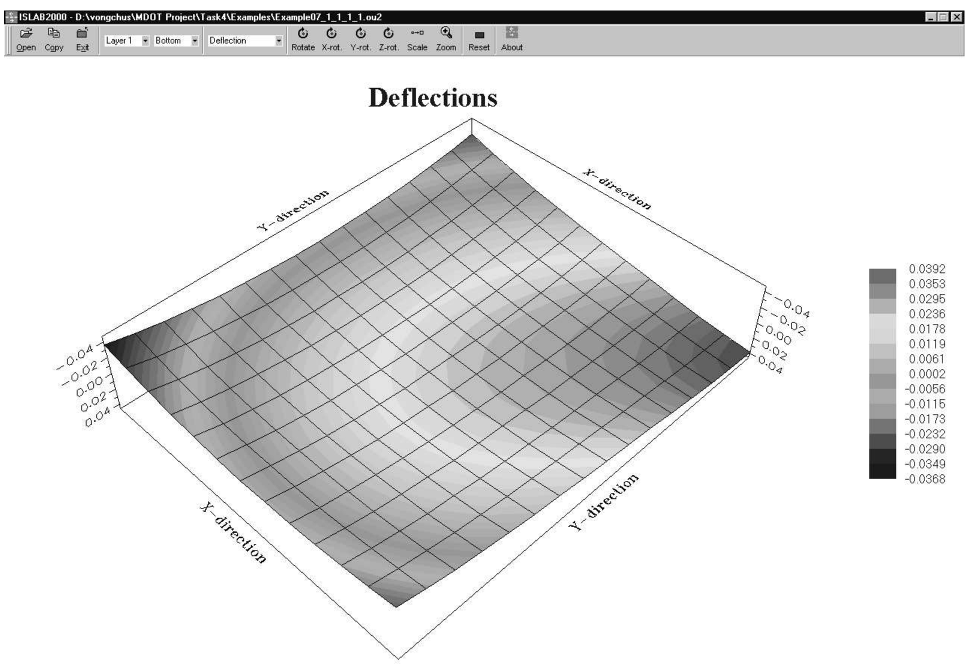


Figure E7-3: Deflection of the PCC Slab, ΔT = -20 °F

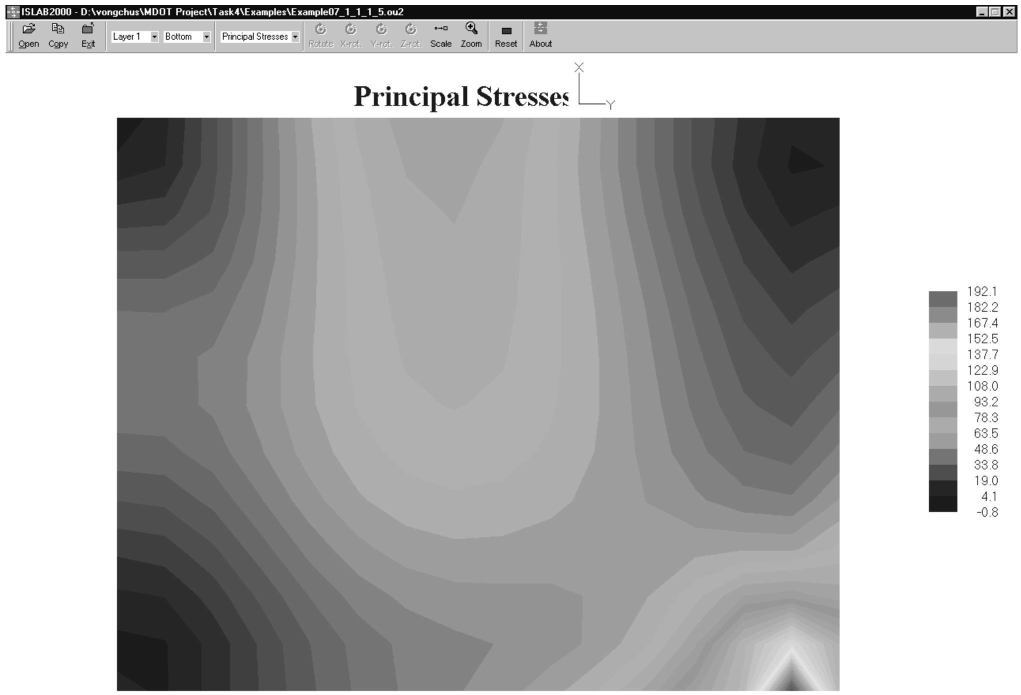


Figure E7-4: Corner Stress at the Top of the PCC Slab, ΔT = +20 °F

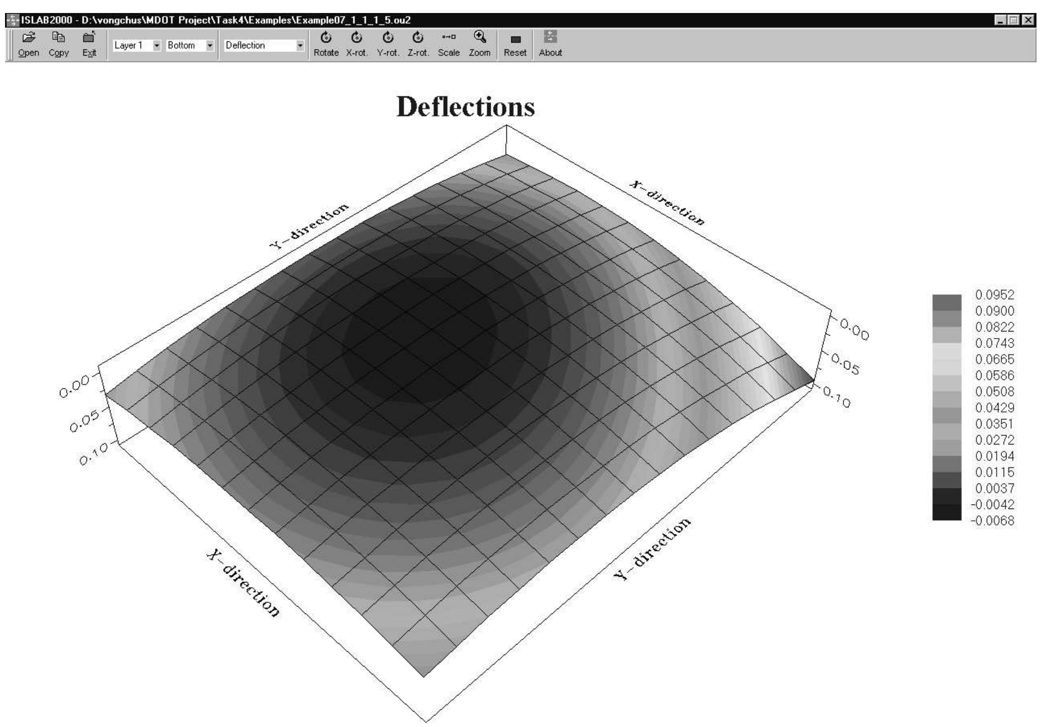
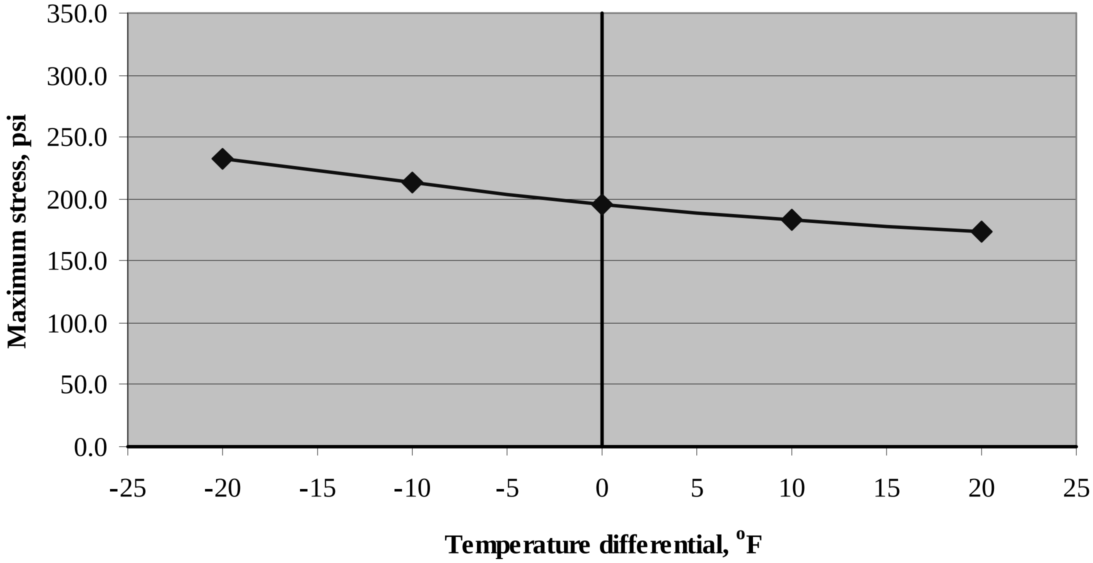
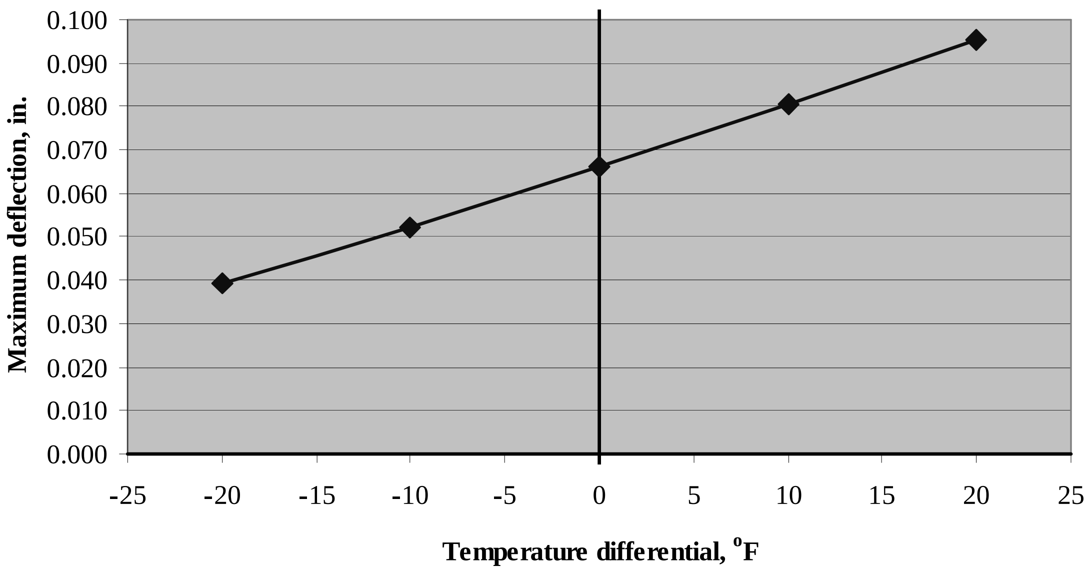


Figure E7-5: Deflection of the PCC Slab, ΔT = +20 °F



E7-6: Relationship Between Stresses and Temperature Differentials



E7-7: Relationship Between Deflections and Temperature Differentials

Example 8:
Single Axle Edge Loading on a Pavement System

Problem Statement

Determine maximum stresses at the bottom of the PCC slab for a pavement system and loading condition as illustrated in Figure E8-1.

Given

Concrete elastic modulus	=	4×10^6	psi
Concrete Poisson's ratio	=	0.15	
Slab thickness	=	10	in.
Base elastic modulus	=	3×10^4	psi
Base Poisson's ratio	=	0.35	
Base thickness	=	16	in.
Lane width	=	144	in.
Shoulder width	=	120	in.
Joint spacing	=	180	in.
Joint design	=	Dowel bars ϕ 1.25 in. @ 12 in. c/c	
AGG factor	=	1×10^6	psi
Mesh size	=	12 x 12	in^2 (medium)
k-value	=	100	psi/in.
Load configuration	=	standard single axle	
Axle weight	=	18	kips
Load location	=	edge loading	
Coefficient of thermal exp., α	=	5×10^{-6}	in./in./^oF
Temperature differential, ΔT	=	none	^oF

Problem Illustration:

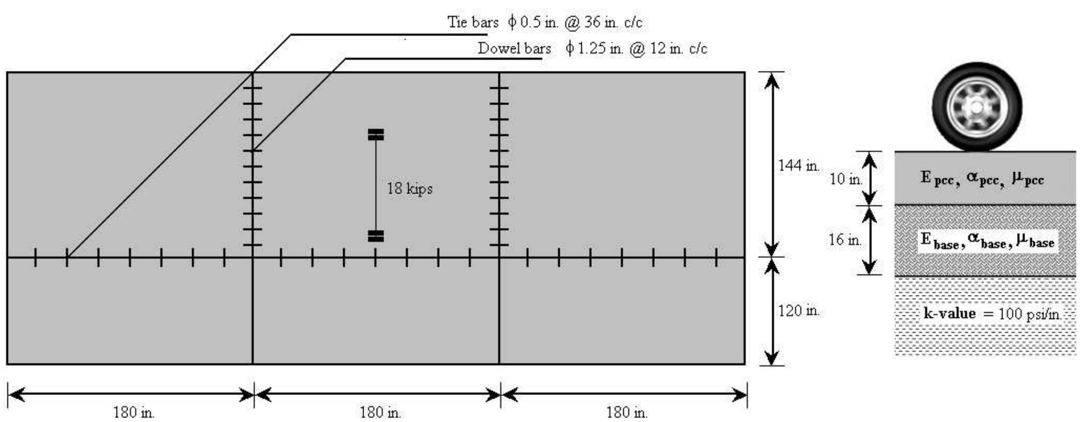


Figure E8-1: Problem Illustration

Solution

Geometry Module

(see Figure E8-2)

Step 1: Click **Geometry** on the main panel to open the geometry module.

Step 2: Click **Insert** twice on the **X-direction** side, and then enter 120 for the shoulder width and 144 for the lane width.

Step 3: Click **Insert** three times on the **Y-direction** side and then enter 180 for the joint spacing.

Step 4: On the geometry panel, select **Medium** to set the mesh size to medium.

Step 5: Click **Generate** to generate the inputs to the input file, and then click **OK** to close the geometry panel.

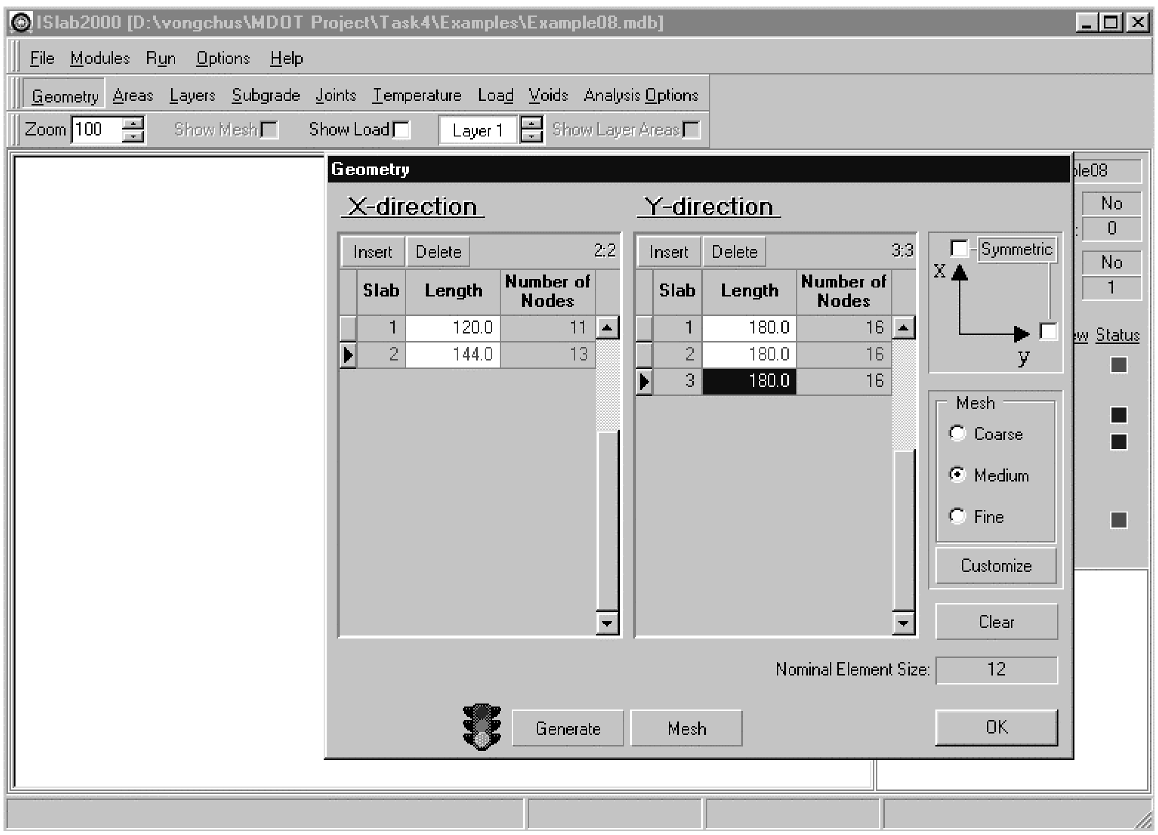


Figure E8-2: Edit Inputs for the Geometry Module

Layers Module

(see Figures E8-3 and E8-4)

Step 1: Click **Layers** to open the layers panel.

Step 2: On the layers panel, type the inputs as identified in the problem statement for the PCC layer.

Step 3: Click **Add Layer** to open the add layer panel. Enter **2** in the **Layer number to add** field, and then click **OK** to close the add layer panel.

Step 4: On the layers panel, select **Layer 2**, and then type the inputs as identified in the problem statement for the base layer.

Step 5: Click **OK** to close the layers panel.

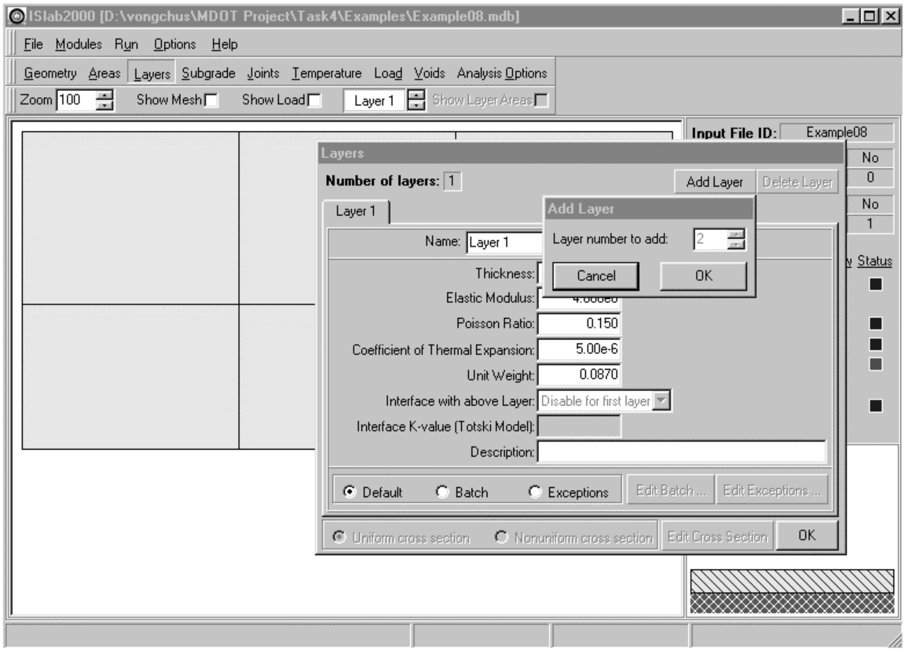


Figure E8-3: Edit Inputs for the Layers Module

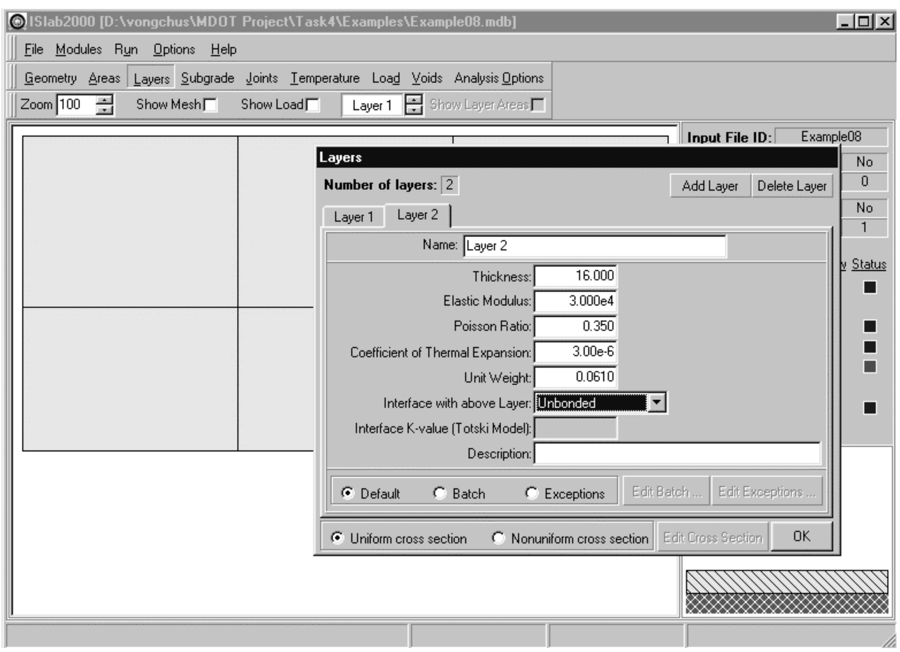


Figure E8-4: Edit Inputs for the Layers Module (continued)

Subgrade Module

(see Figure E8-5)

Step 1: Click **Subgrade** to open the subgrade panel.

Step 2: Enter the inputs as identified in the problem statement.

Step 3: Click **OK** to close the subgrade panel.

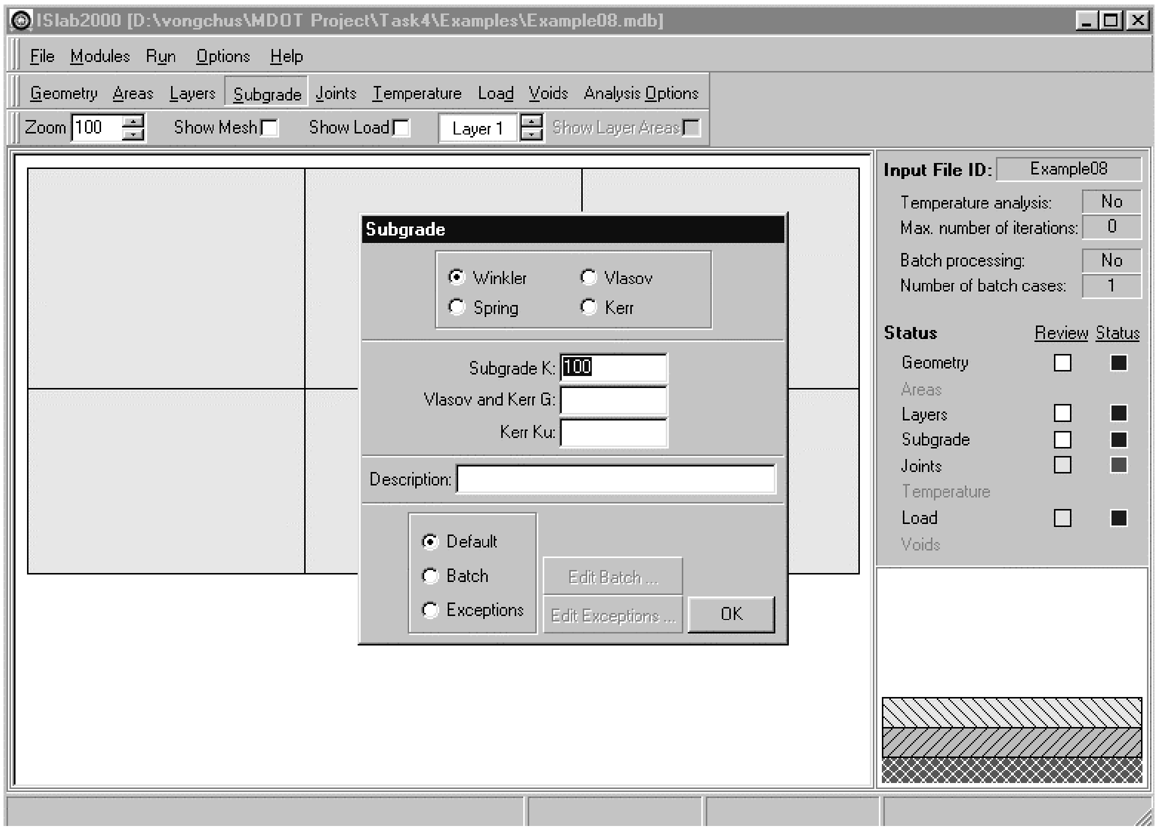


Figure E8-5: Edit Inputs for the Subgrade Module

Joints Module

(see Figures E8-6 through E8-9)

Step 1: Click **Joints** to open the joints module.

Step 2: Under **Joints in x-direction**, select **Specify joint parameters**, select **AGG Interlock** in the **Joint type** field, and then enter 1 x 10^6 (**1E6**) in the **AGG factor** field.

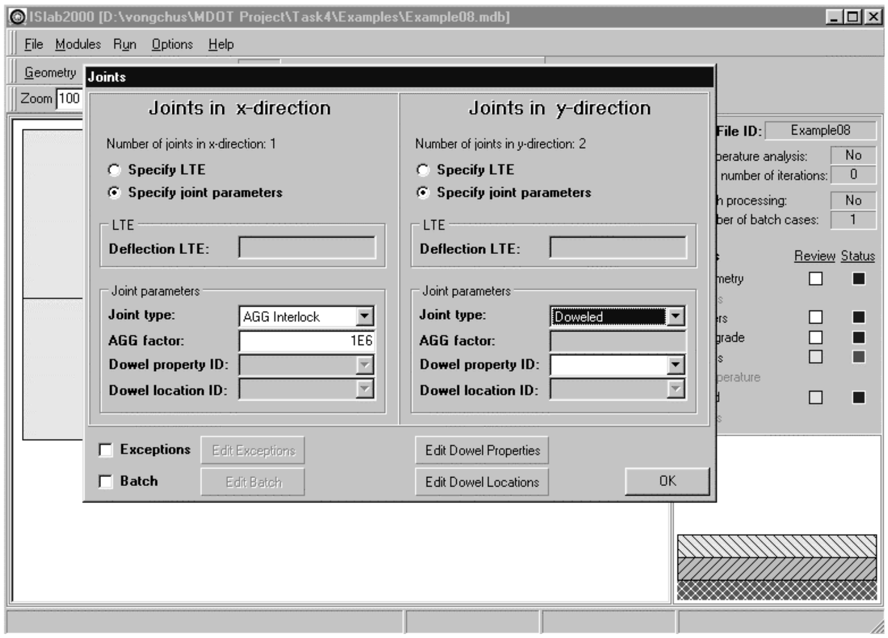


Figure E8-6: Edit Inputs for the Joints Module

Step 3: Under **Joints in y-direction**, select **Specify joint parameters**, select **Doweled** in the **Joint type** field, and then click **Edit Dowel Locations** to open the dowel locations panel (see Figure E8-7.)

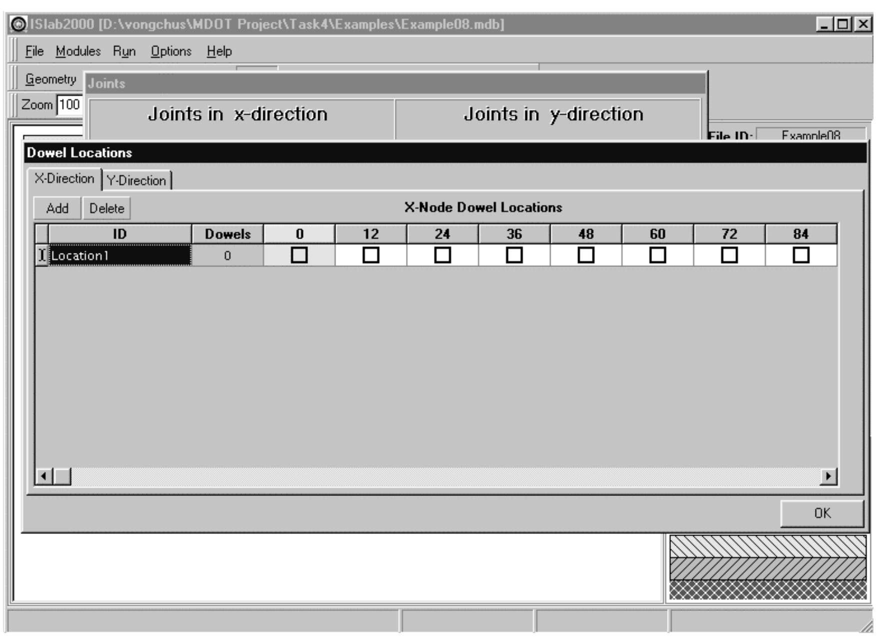


Figure E8-7: Edit Inputs for the Joints Module (continued)

Step 4: On the dowel locations panel, select the **X-Direction** tab, and then click **Add**. Enter “Location1” in the **ID** field, and then double click on the locations 132, 144… 252. Leave all the locations in the shoulder (locations 12, 24…108) blank (see Figure E8-8). Click **OK** to close the dowel location panel.

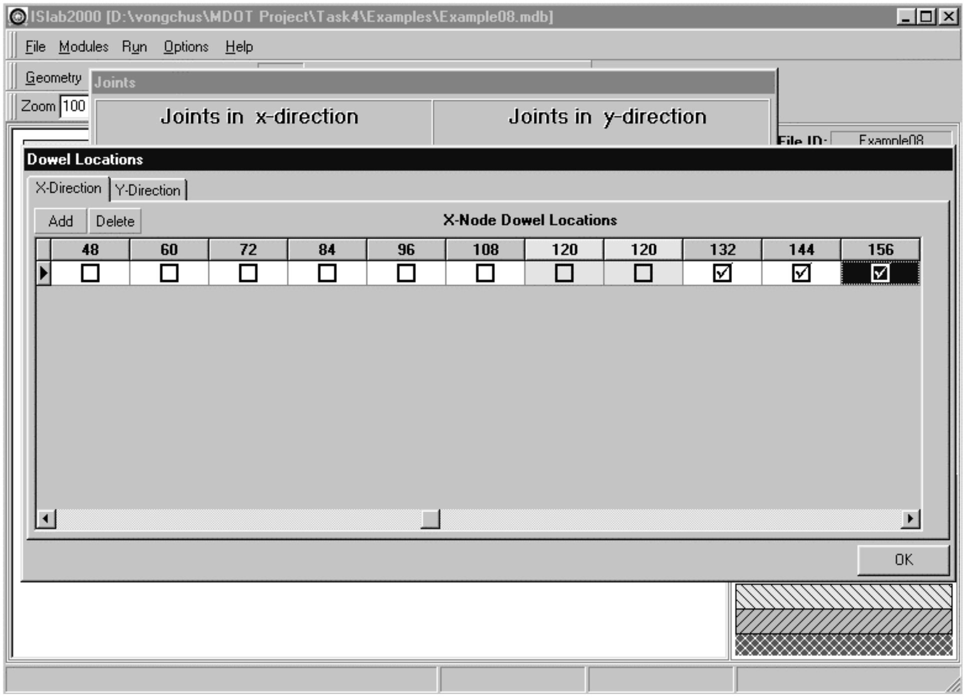


Figure E8-8: Edit Inputs for the Joints Module (continued)

Step 5: Select **Dowel1** in the **Dowel property ID** field, select **Location1** in the **Dowel location ID** field, and then click **OK** to close the joints panel (see Figure E8-9).

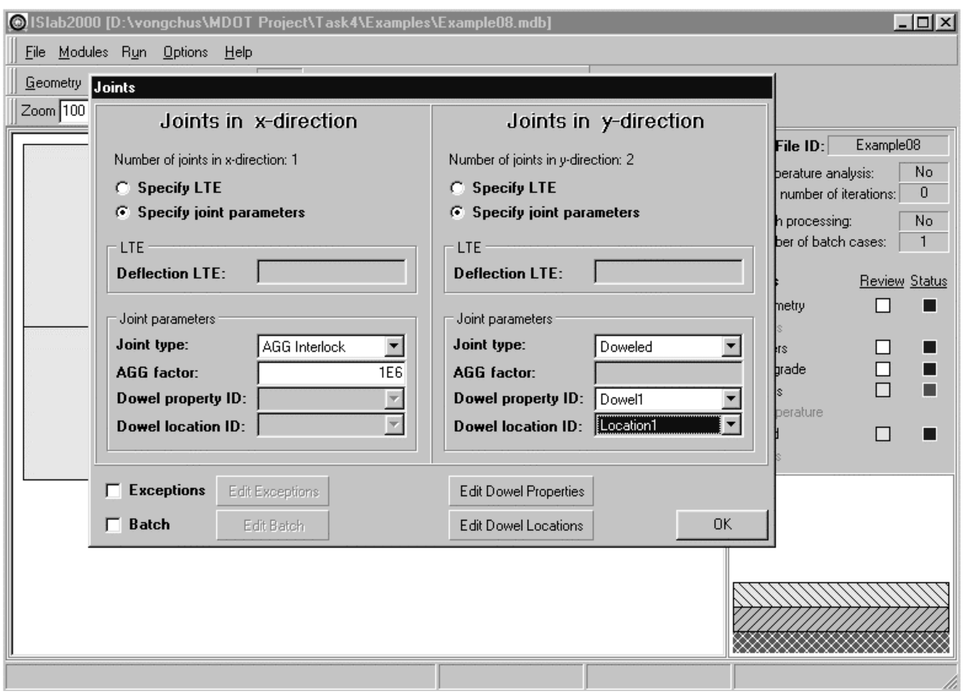


Figure E8-9: Edit Inputs for the Joints Module (continued)

Load Module

(see Figure E8-10 and E8-11)

Step 1: Click **Load** to open the load panel.

Step 2: On the load panel, click **Axle Design** to open the axle design panel (see Figure E8-10.) Enter “Single Axle” in the **Axle Name** field.

Step 3: Type the tire pressure in the **Tire Pressure** field. The tire pressure of the wheel load can be computed as shown below (for more detail, see standard configuration of single axle):

$$Tire\ Pressure = \frac{Wheel\ Load}{Contact\ \ Area} = \frac{4{,}500\ lbs}{5\ in. \times 10\ in.} = 90\ \ psi$$

Step 4: Enter the tire width in the **Tire Width** field (5 in. for this example).

Step 5: Enter wheel spacing information as shown in Figure E8-10.

Step 6: Select **Bottom Left** for the reference point position.

Step 7: Click **OK** to close the axle design panel.

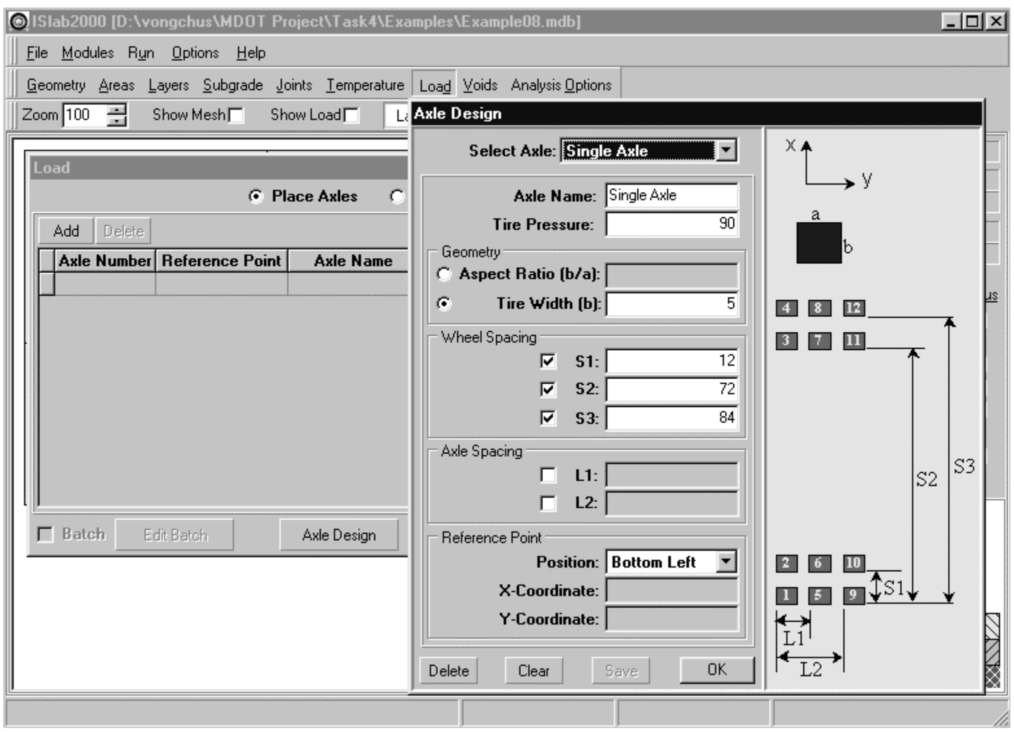


Figure E8-10: Edit Inputs for the Load Module

Step 8: On the load panel, click on **Add** to add an axle (see Figure E8-11).

Step 9: Select **Single Axle** in the **Axle Name** field.

Step 10: Enter an X-location and a Y-location to locate the wheel load. The X- and Y-location for an edge loading condition can be computed as shown below:

$$X-location = Shoulder\ width + Distance\ dual\ wheel\ center\ to\ shoulder$$
$$- Distance\ dual\ wheel\ center\ to\ reference\ point$$

$$= 120 + 20 - \left(\frac{5}{2} + \frac{12}{2}\right) = 131.5\ in$$

$$Y-location = Joint\ spacing + \frac{Joint\ spacing}{2} - \frac{wheel\ load\ length}{2}.$$

$$= 180 + \frac{180}{2} - \frac{10}{2} = 265\ in$$

Step 11: Enter the load for the single axle (18,000 lbs for this example).

Step 12: Click **OK** to close the load panel.

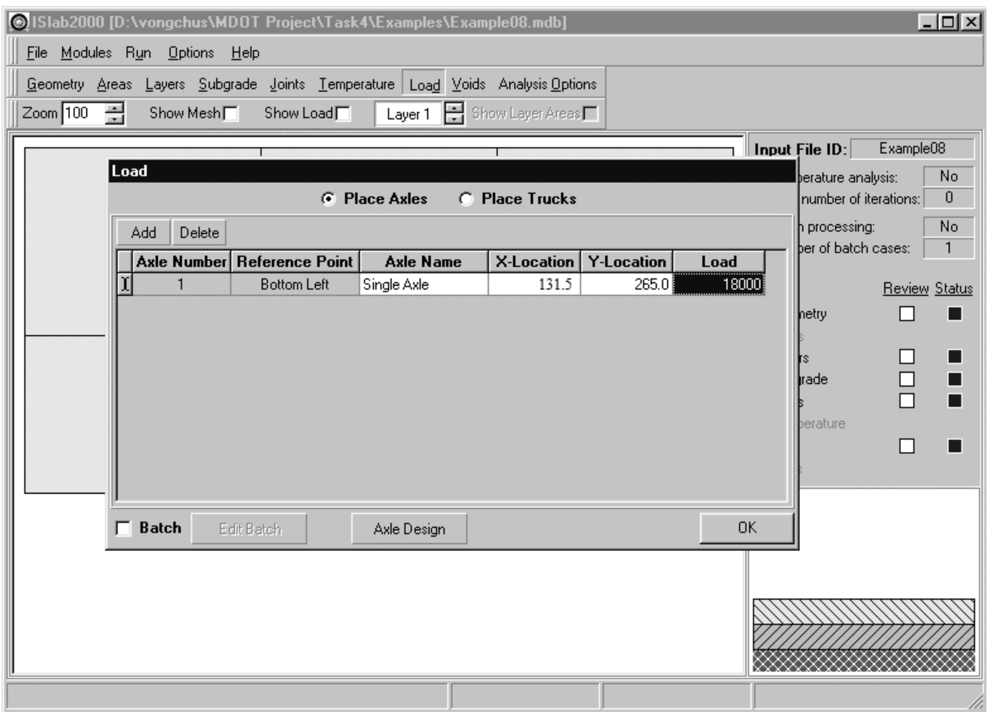


Figure E8-11: Edit Inputs for the Load Module (continued)

Temperature Module

Temperature module is not required for this problem.

Analysis Options Module

Use this module from Example 4.

The main panel should display the pavement structure, loading condition, and meshing as shown in Figure E8-12.

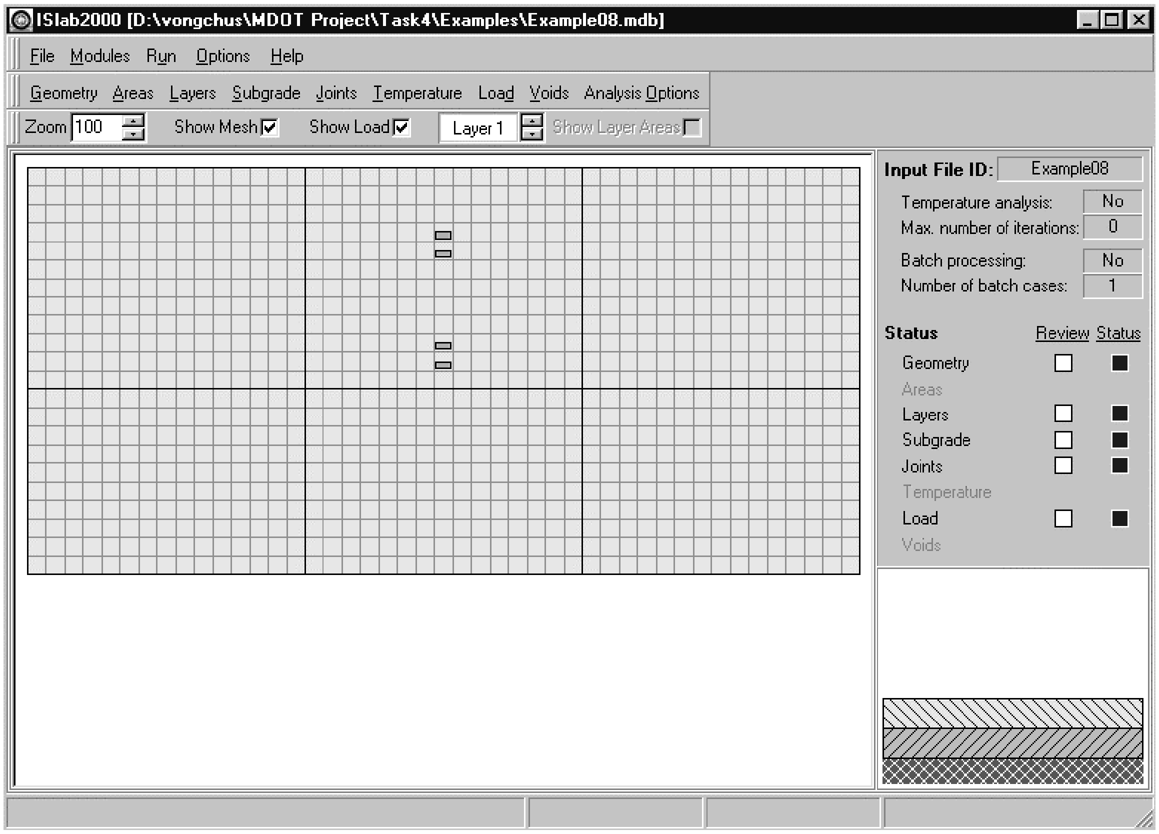


Figure E8-12: Main Panel After the Completion of Inputs

Analysis Results

Maximum transverse stress at the bottom of the PCC slab (see Figure E8-13)	=	72.1 psi
Maximum longitudinal stress at the bottom of the PCC slab (see Figure E8-14)	=	114.5 psi

> **NOTE**
> Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Stress and deflection contours from ISLAB2000 are also shown in Figures E8-13 through E8-15.

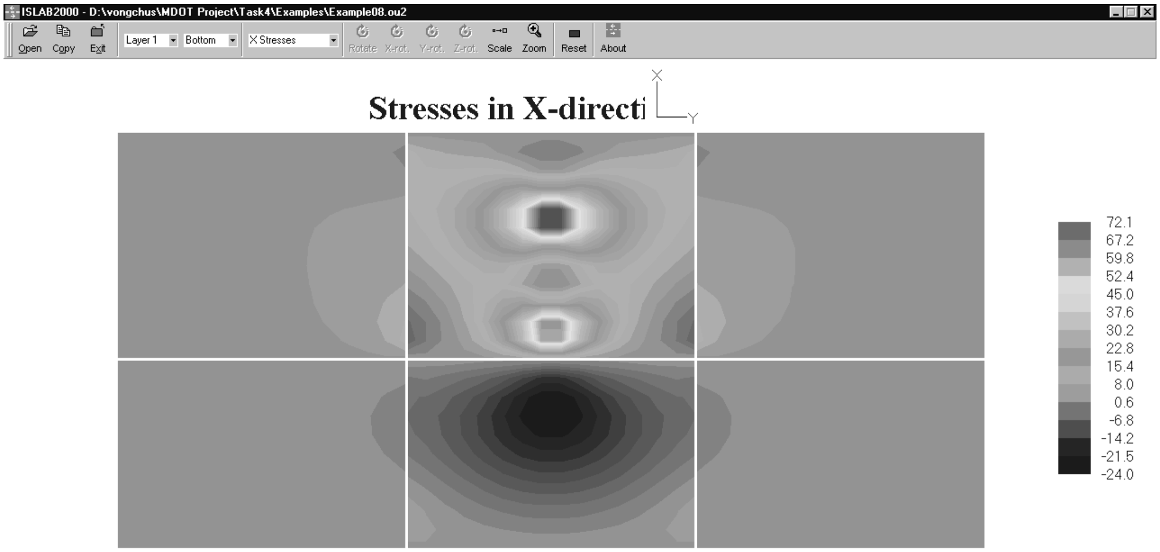


Figure E8-13: Transverse Stress at the Bottom of the PCC Slab

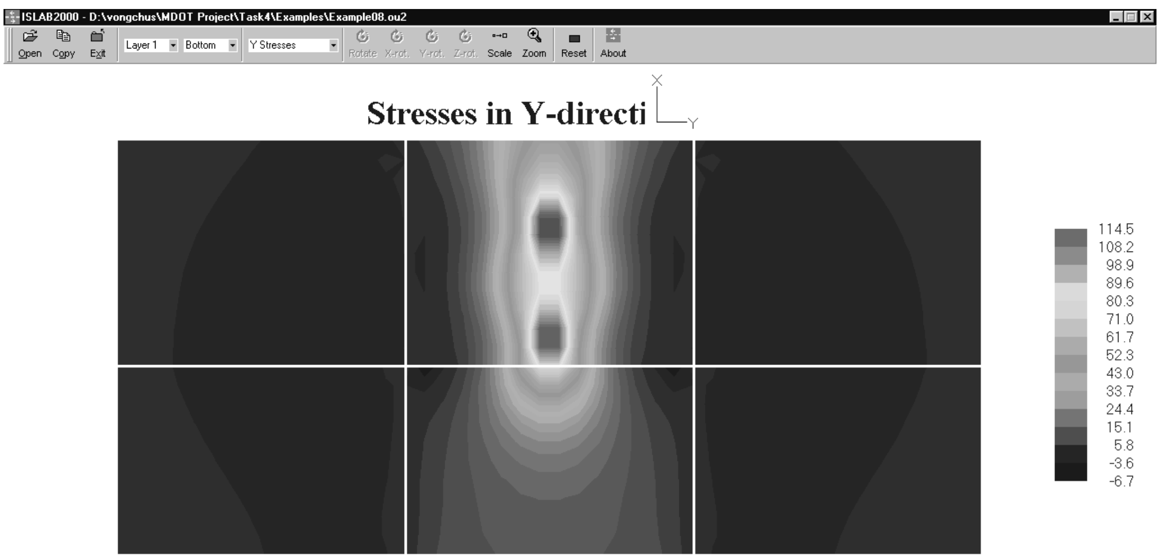


Figure E8-14: Longitudinal Stress at the Bottom of the PCC Slab

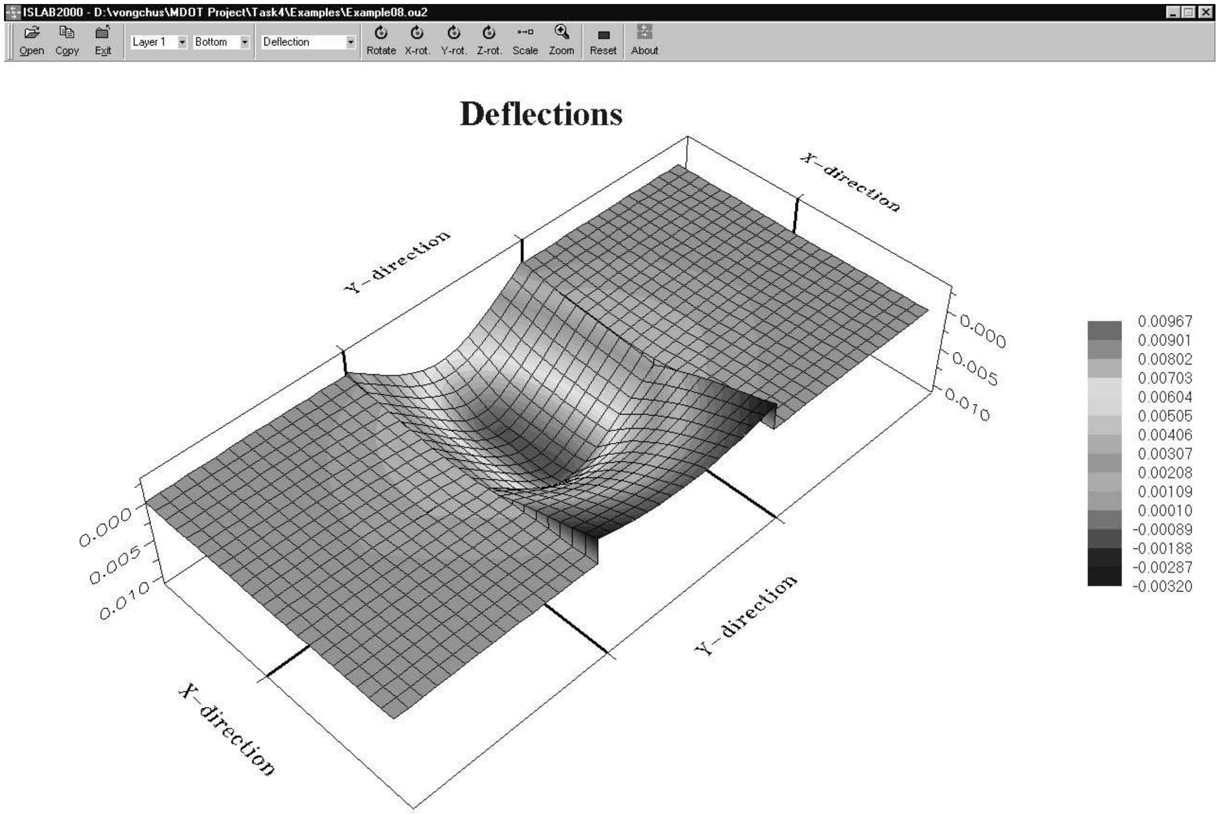


Figure E8-15: Deflection of the PCC Slab

Example 9:
Single Axle Edge Loading with Thermal Gradients

Problem Statement

Determine maximum stresses at the bottom of the PCC slab for the pavement system and loading condition in Example 8 considering temperature differentials, ΔT, of 0, +10, +20 ^{o}F.

Given

Temperature differential, ΔT = 0, +10, +20 ^{o}F

Problem Illustration

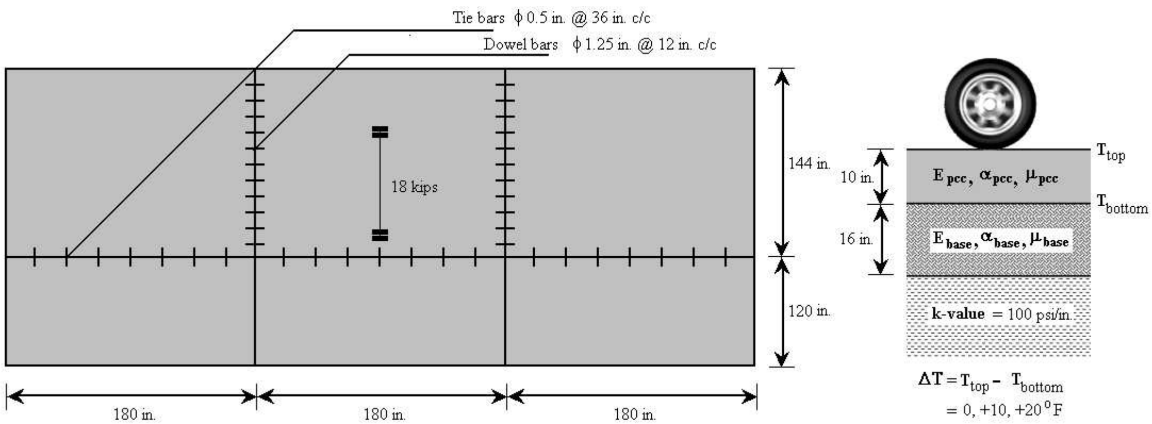


Figure E9-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 8.

Layers Module

Use this module from Example 8.

Subgrade Module

Use this module from Example 8.

Joints Module

Use this module from Example 8.

Load Module

Use this module from Example 8.

Temperature Module

(see Figures E9-2 and E9-3)

Step 1: Click **Temperature** to open the temperature panel.

Step 2: On the temperature module, select **Perform Temperature Analysis** and **Batch**.

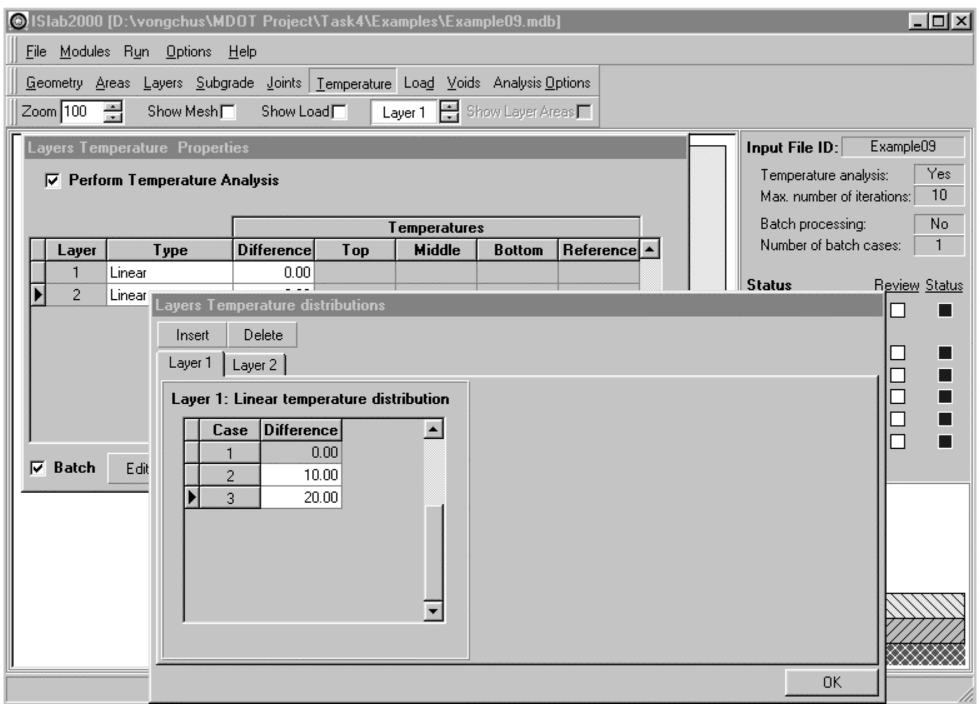


Figure E9-2: Edit Inputs for the Temperature Module

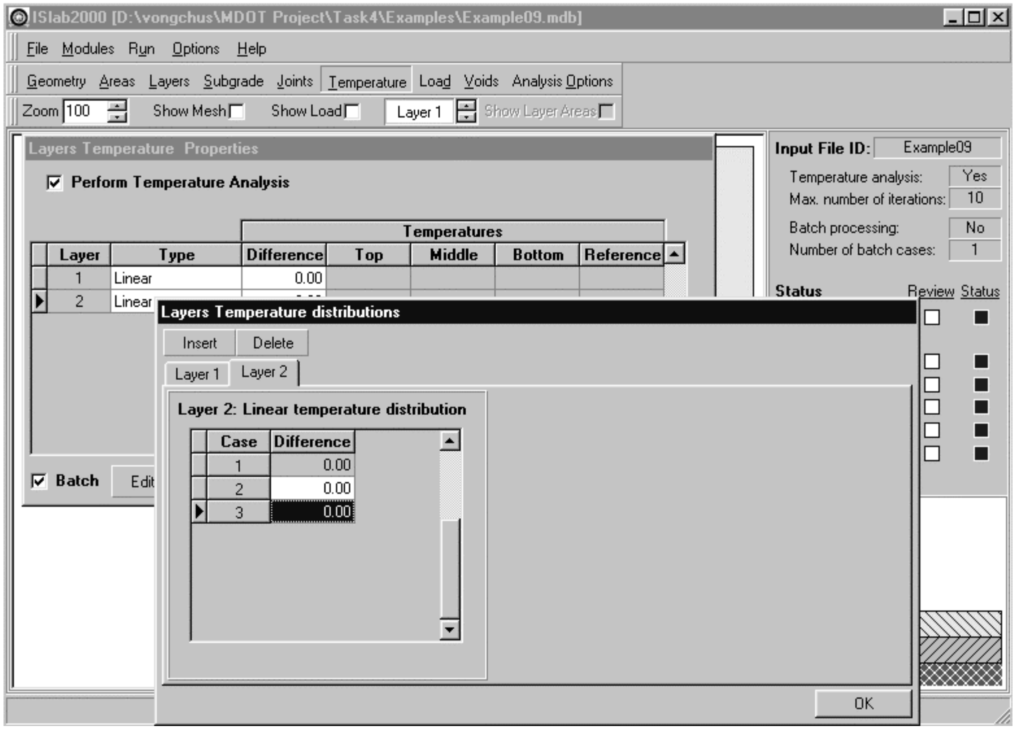


Figure E9-3: Edit Inputs for the Temperature Module (continued)

Step 3: In the **Difference** field, enter the temperature differential of the first case (0 ^{o}F for this problem).

Step 4: Click **Edit Batch** to open the Layers temperature distributions panel.

Step 5: On the **Layer 1** tab of the layers temperature distributions panel, click **Insert** two times to add two more cases of temperature differential, and then, enter the other two temperature differentials as identified in the problem statement.

Step 6: On the **Layer 2** tab of the layers temperature distributions panel, enter zero (**0**) in the other two temperature differentials across the base layer.

Step 7: Click **OK** to close the layers temperature distributions panel.

Step 8: Click **OK** at the bottom right of the layers temperature properties panel. The panel will disappear.

Analysis options module

Use this module from Example 4.

The main panel should display the pavement structure, loading condition, and meshing as shown in Example 8, Figure E8-12.

Analysis Results

ΔT, °F	Stress at the bottom of the PCC, psi	
	Transverse	Longitudinal
0	72.1	114.5
10	105.9	169.5
20	139.7	224.5

Table E9-1: Analysis Results

NOTE
Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Stress and deflection contours from ISLAB2000 are also available in Figures E9-4 through E9-6. Figure E9-10 illustrates relationship between maximum stresses and temperature differentials.

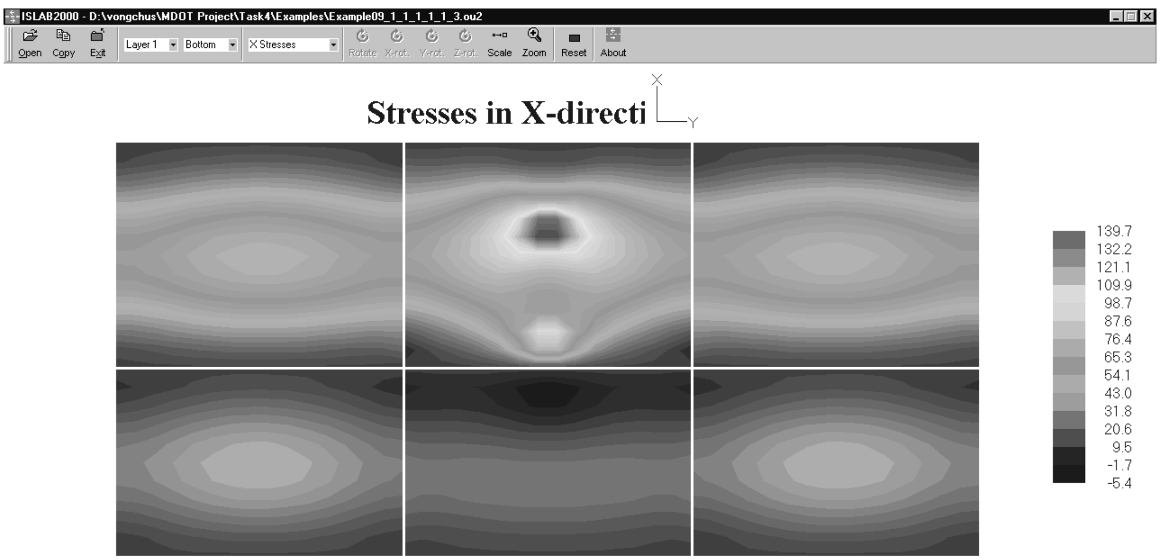


Figure E9-4: Transverse Stress at the Bottom of the PCC Slab

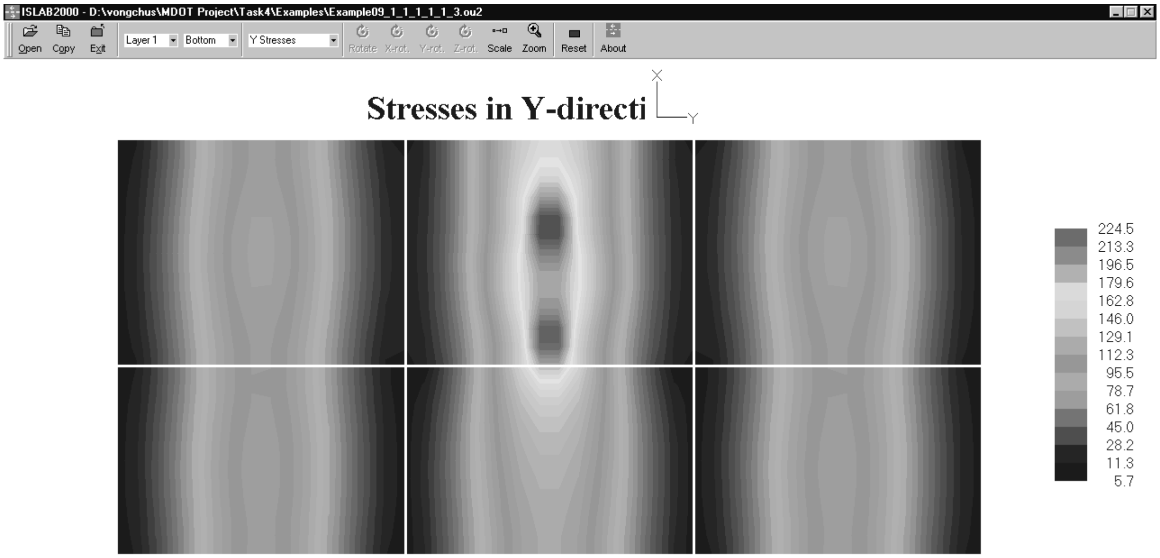


Figure E9-5: Longitudinal Stress at the Bottom of the PCC Slab

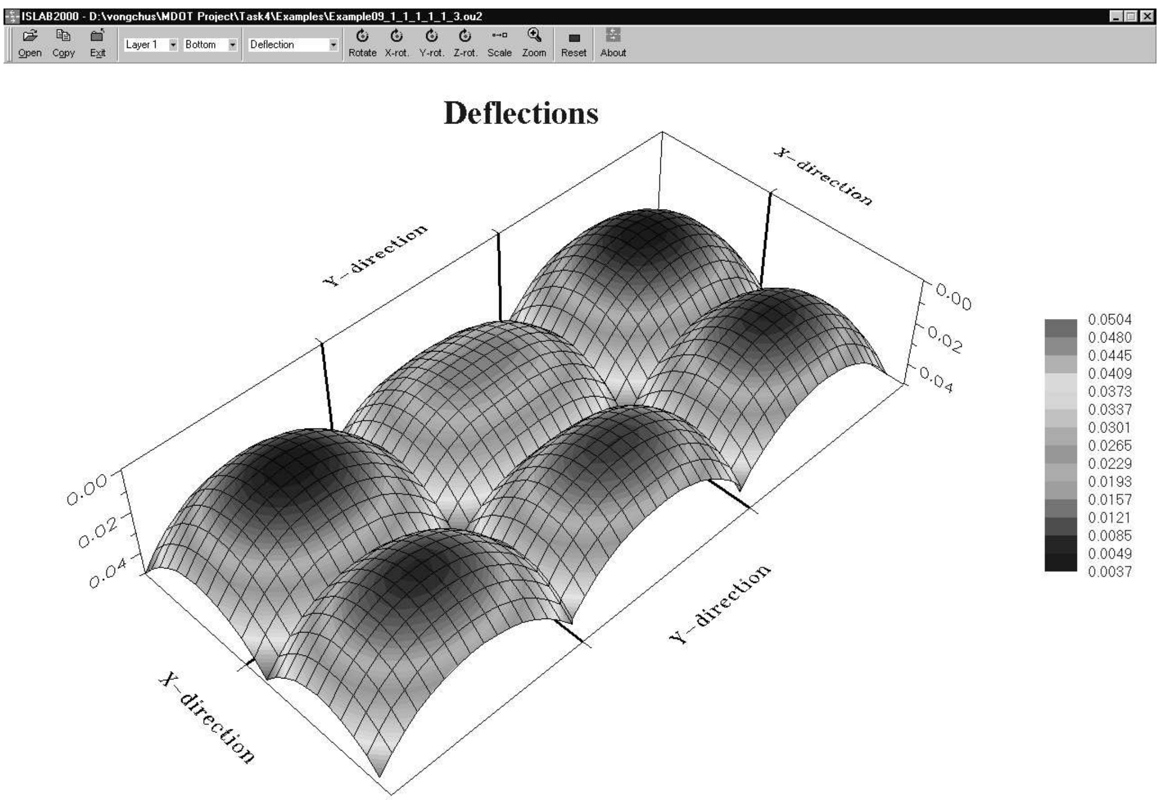
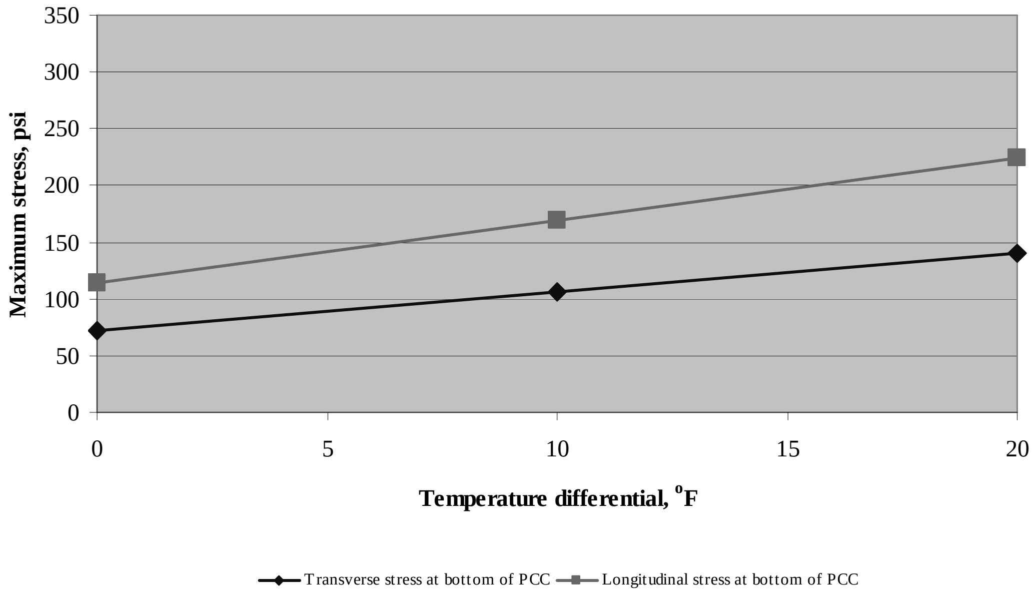


Figure E9-6: Deflection of the PCC Slab



E9-10: Relationship Between Stresses and Temperature Differentials

Example 10:
Single Axle Corner Loading with Thermal Gradients

Problem Statement

Determine maximum stresses at the top of the PCC slab for the pavement system in Example 8 but apply corner loading condition considering temperature differentials, ΔT, of -20, -10, and 0 ^{o}F.

Given

Temperature differential, ΔT = -20, -10, 0 ^{o}F

Problem Illustration

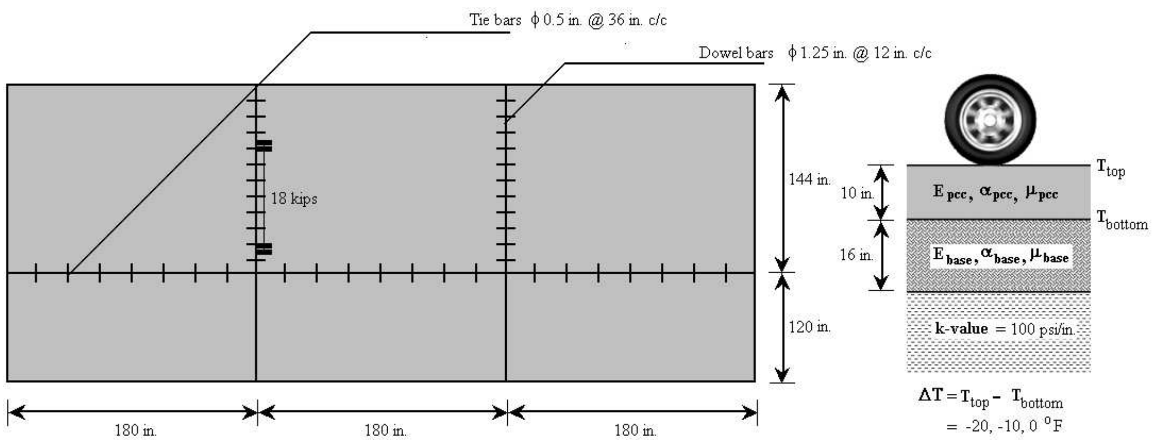


Figure E10-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 8.

Layers Module

Use this module from Example 8.

Subgrade Module

Use this module from Example 8.

Joints Module

Use this module from Example 8.

Load Module (see Figure E10-2)

Step 1: Follow steps 1 through 7 from the Load Module in Example 8.

Step 2: On the load panel (see Figure E8-11), click **Add** to add an axle.

Step 3: Select **Single Axle** in the **Axle Name** field.

Step 4: Enter an X-location and Y-location to locate the wheel load. The X-location and Y-location for an edge loading condition can be computed as shown below:

$$X - location = Shoulder\ width + Distance\ dual\ wheel\ center\ to\ shoulder$$
$$- Distance\ dual\ wheel\ center\ to\ reference\ point$$

$$= 120 + 20 - \left(\frac{5}{2} + \frac{12}{2}\right) = 131.5\ in$$

$$Y - location = Joint\ spacing$$

$$= 180$$

Step 5: Enter the load for the single axle (18,000 lbs for this example).

Step 6: Click **OK** to close the load panel.

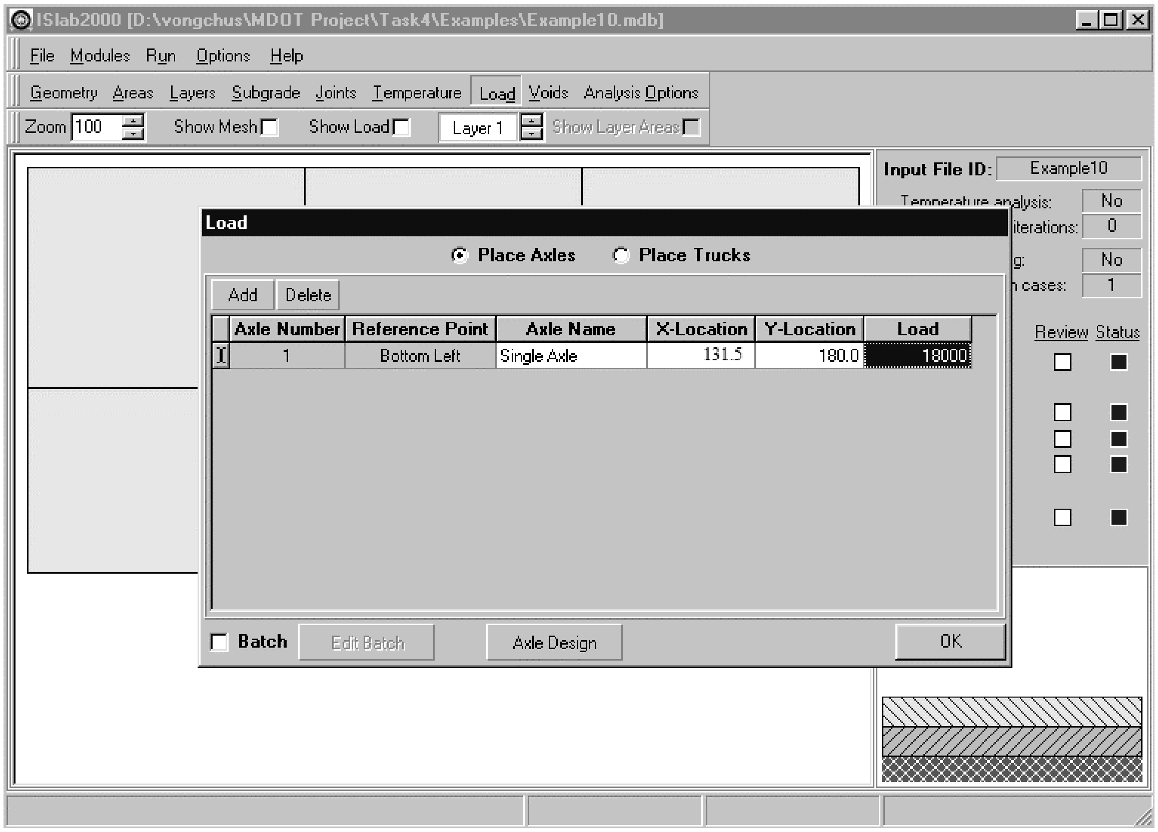


Figure E10-2: Edit Inputs for the Load Module

Temperature Module

(see Figures E9-2 and E9-3)

Step 1: Click **Temperature** to open the temperature properties panel.

Step 2: On the temperature properties panel, select the **Perform Temperature Analysis** and **Batch** check boxes.

Step 3: Enter the temperature differential of the first case in the **Difference** field (-20 ^{o}F for this example).

Step 4: Click **Edit Batch** to open the layers temperature distributions panel.

Step 5: On the **Layer 1** tab of the layers temperature distributions panel, click **Insert** two times to add two more cases of temperature differential, and then type the other two temperature differentials as identified in the problem statement.

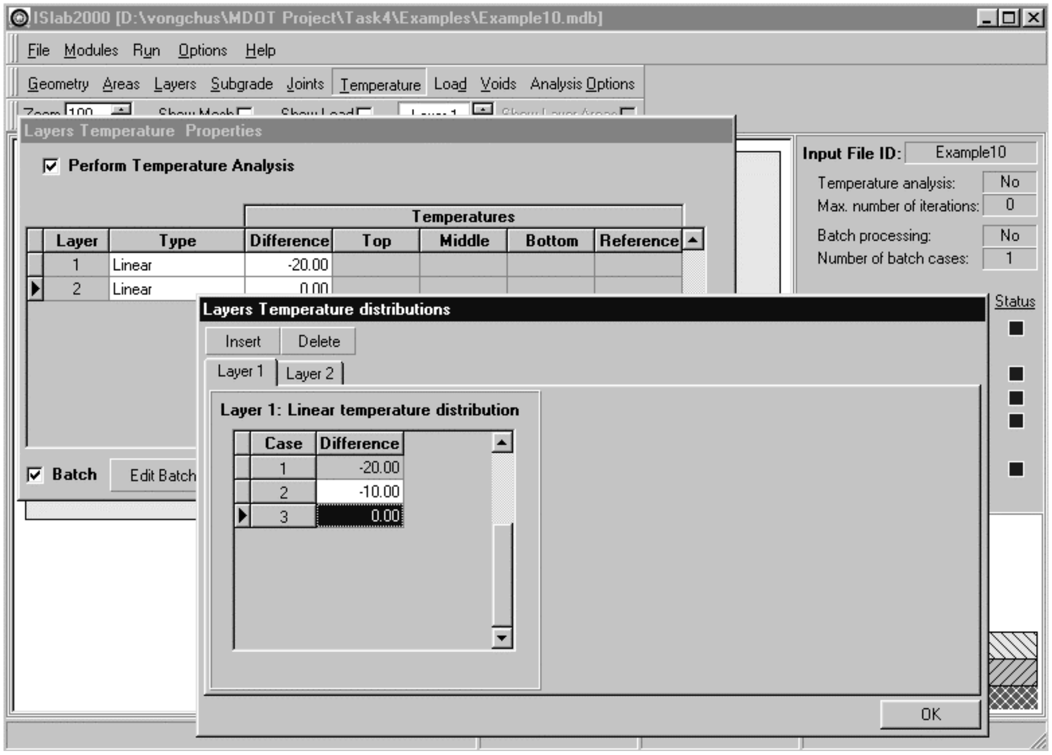


Figure E10-3: Edit Inputs for the temperature module

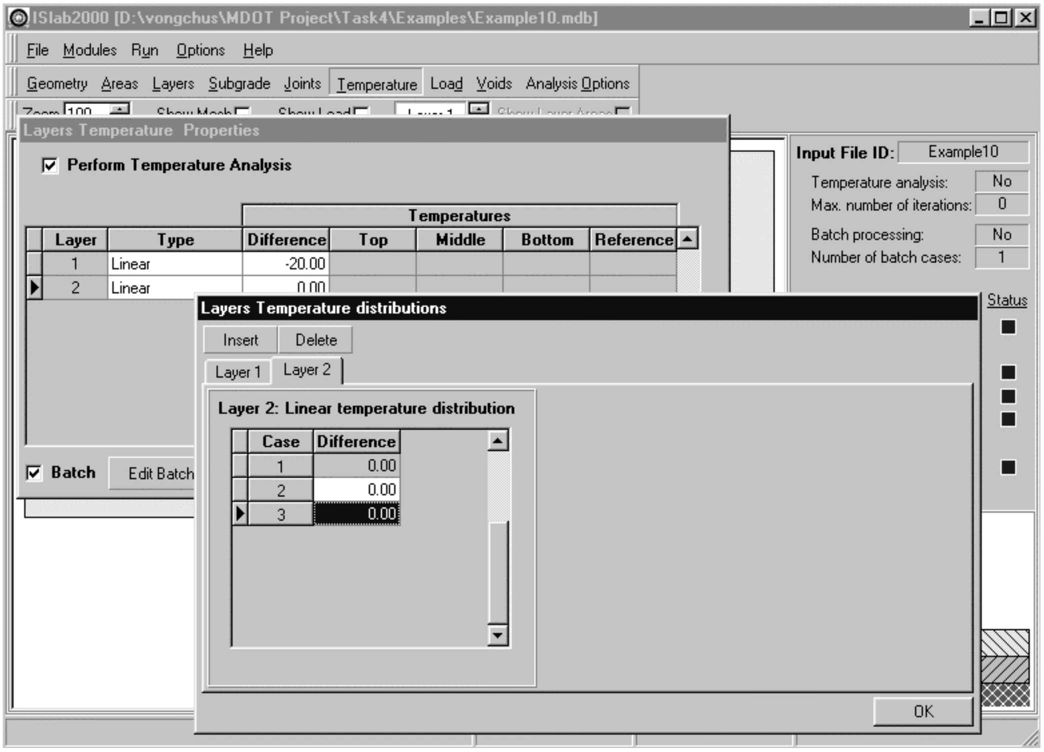


Figure E10-4: Edit Inputs for the Temperature Module (continued)

Step 6: On the **Layer 2** tab of the layers temperature distributions panel, enter zero (**0**) in the other two temperature differentials across the base layer.

Step 7: Click **OK** to close the layers temperature distributions panel.

Step 8: Click **OK** to close the layers temperature properties panel.

Analysis Options Module

Use this module from Example 4.

The main panel should display the pavement structure, loading condition, and meshing as shown in Figure E10-5.

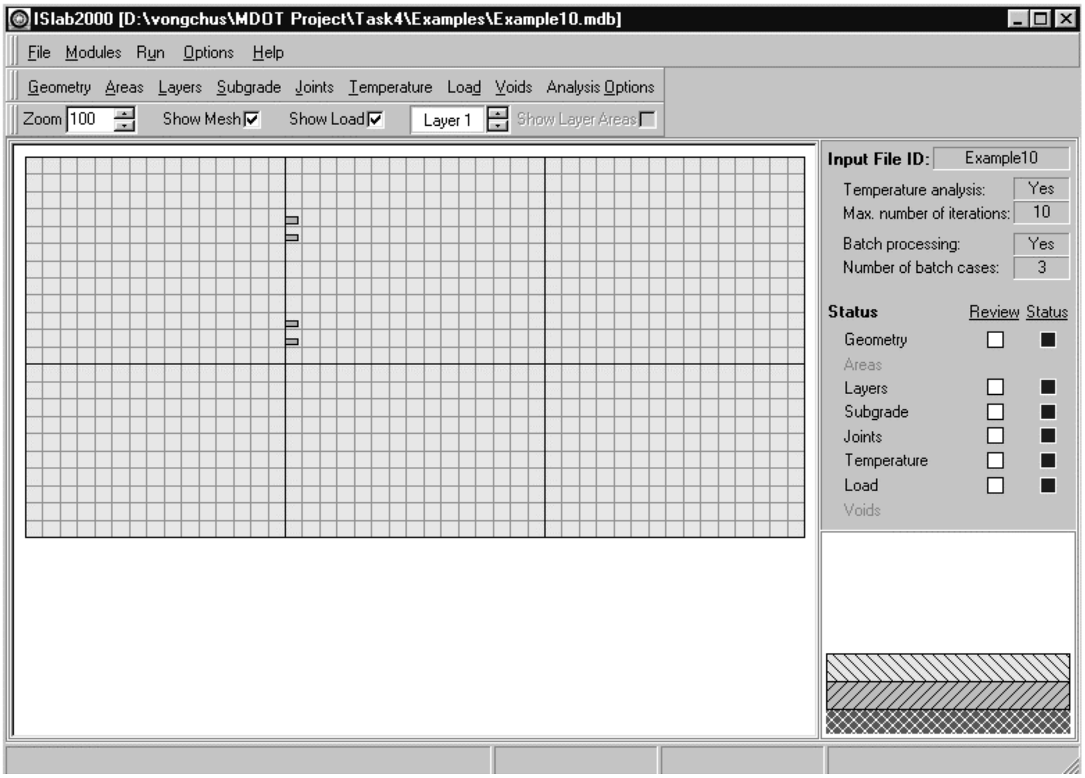


Figure E10-5: Main Panel After the Completion of Inputs

Analysis Results

ΔT, °F	Stress at the top of the PCC, psi	
	Transverse	Longitudinal
-20	87.9	148.4
-10	63.2	95.2
0	38.9	47.5

Table E10-1: Analysis Results

NOTE

Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Stress and deflection contours from ISLAB2000 are also available in Figures E10-6 through E10-8. Figure E10-9 illustrates relationship between maximum stresses and temperature differentials.

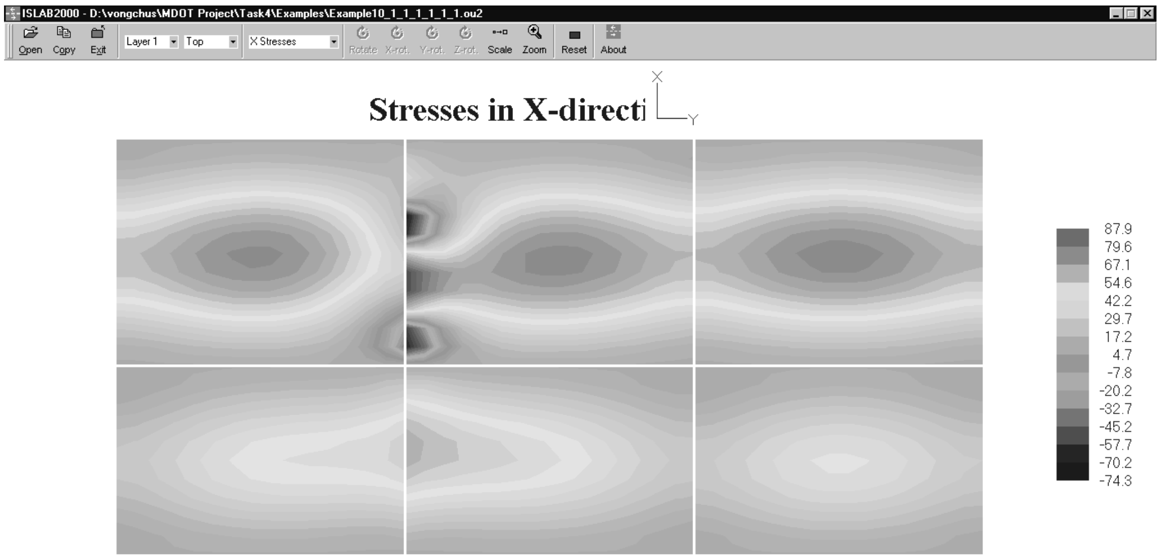


Figure E10-6: Transverse Stress at the Top of the PCC Slab

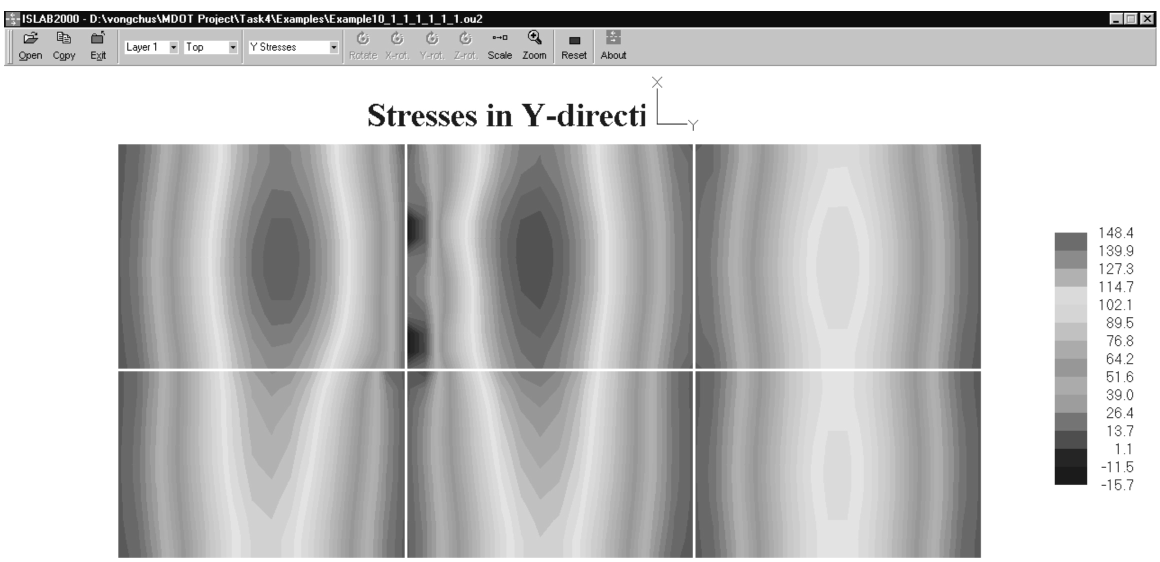


Figure E10-7: Longitudinal Stress at the Top of the PCC Slab

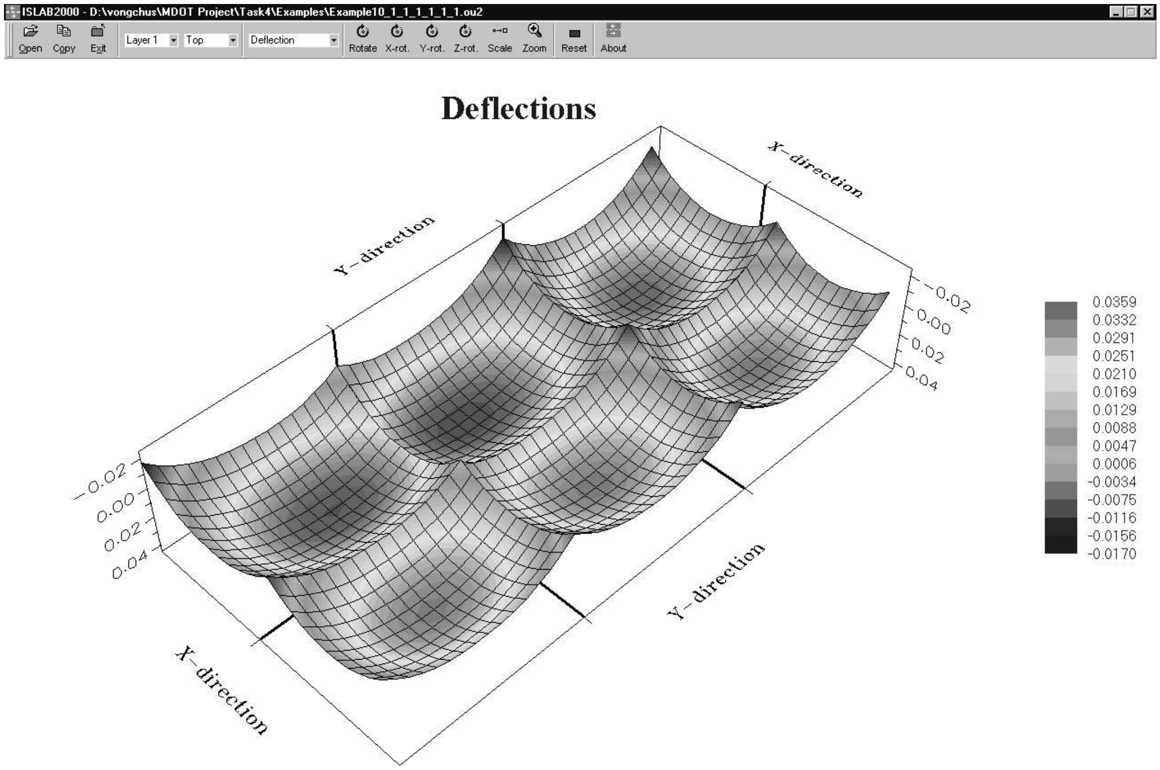
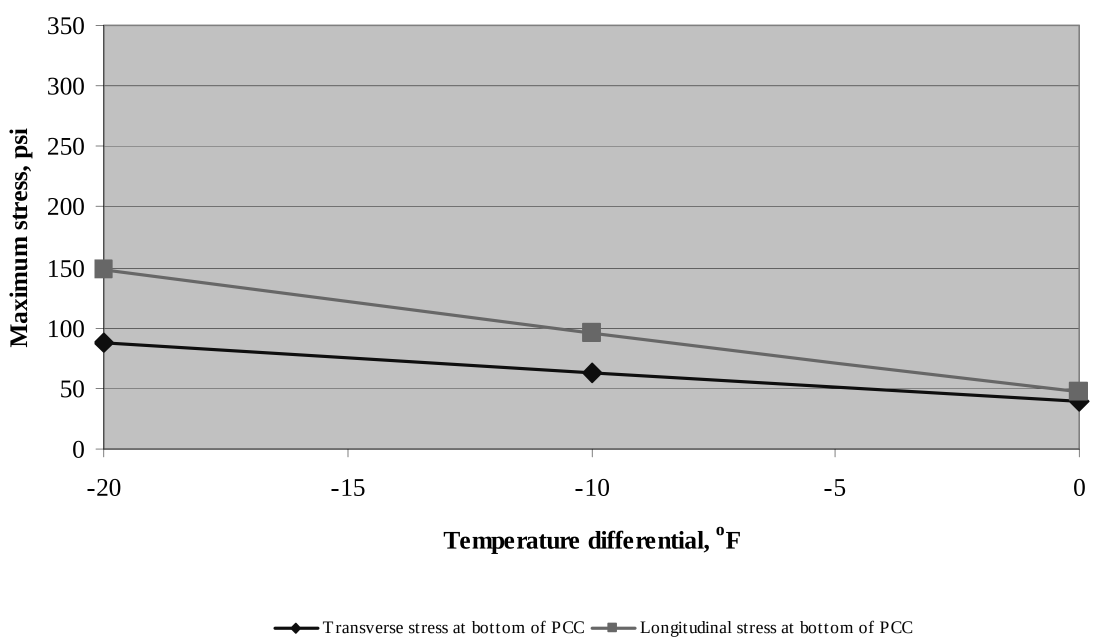


Figure E10-8: Deflection of the PCC Slab



E10-9: Relationship Between Stresses and Temperature Differentials

Example 11:
Single Axle Edge Loading with Various PCC Edge Thicknesses

Problem Statement

Determine maximum stresses at the bottom of the PCC slab for the pavement system and loading condition in Example 8 considering PCC thickness = 6, 8, 10, 12 in.

Given

PCC thickness	=	6, 8, 10, 12	in.

Problem Illustration

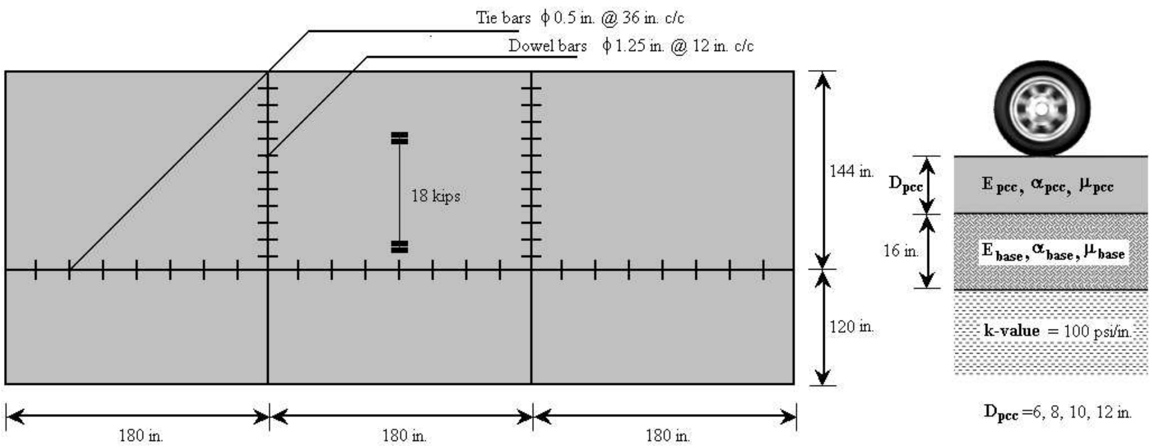


Figure E11-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 8.

Layers Module

(see Figures E11-2 and E11-3)

Step 1: Click **Layers** to open the layers panel.

Step 2: On the layers panel, enter the inputs as identified in the problem statement for the PCC layer.

Step 3: Click **Add Layer** to open the layer panel, enter **2** in the **Layer number to add** field, and then select **OK**.

Step 4: On the layers panel, select the **Layer 2** tab, and then enter the inputs as identified in the problem statement for the base layer.

Step 5: On the layers panel, select the **Layer 1** tab, select **Batch**, and then click **Edit Batch** to open the layer 1 properties panel (see Figure E11-2).

Step 6: On the layer 1 properties panel click **Insert** three times to add three additional cases, and then type the PCC thicknesses as identified in the problem statement. (see Figure E11-3)

Step 7: Click **OK** to close the layer 1 properties panel, and then click OK to close the layers panel.

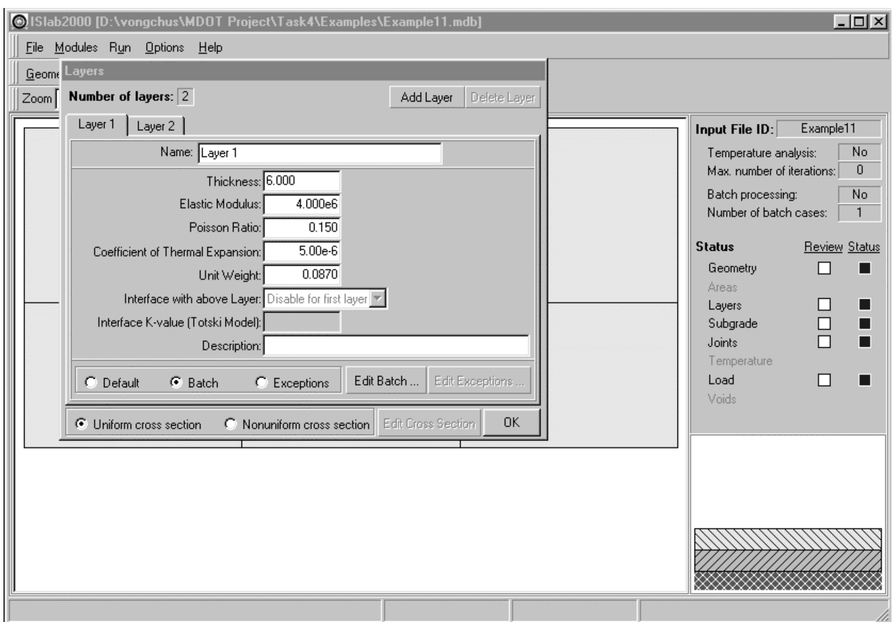


Figure E11-2: Edit Inputs for the Layers Module

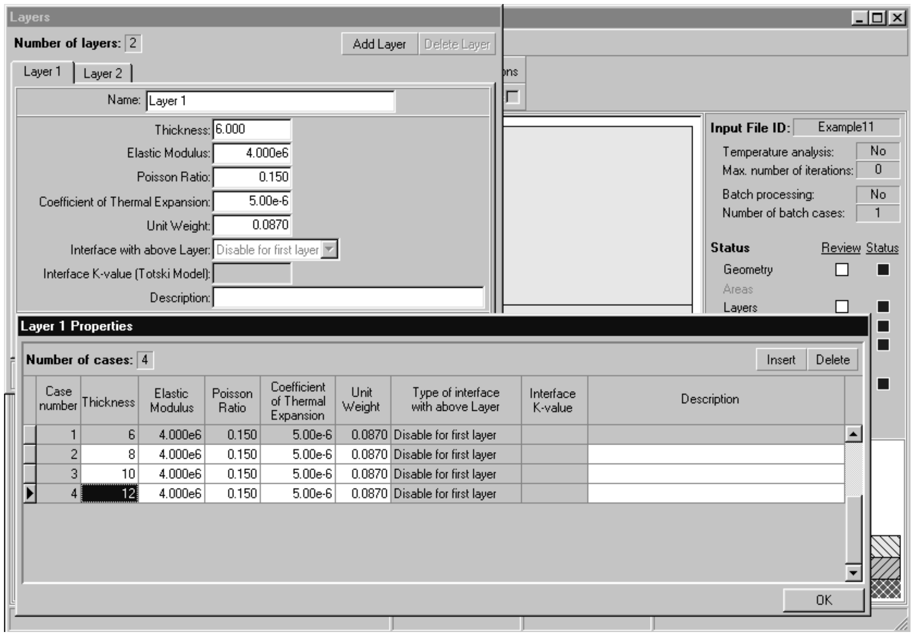


Figure E11-3: Edit Inputs for the Layers Module (continued)

Subgrade Module

Use this module from Example 8.

Joints Module

Use this module from Example 8.

Load Module

Use this module from Example 8.

Temperature Module

This module is not required for this problem.

Analysis Options Module

Use this module from Example 4.

The main panel should display the pavement structure, loading condition, and meshing as shown in Example 8, Figure E8-12.

Analysis Results

PCC thickness, in.	Stress at the bottom of the PCC, psi	
	Transverse	Longitudinal
6	151.8	199.3
8	102.3	148.0
10	72.1	114.5
12	52.8	90.9

Table E11-1: Analysis Results

NOTE

Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Figure E11-4 illustrates relationship between maximum stresses and PCC thickness.

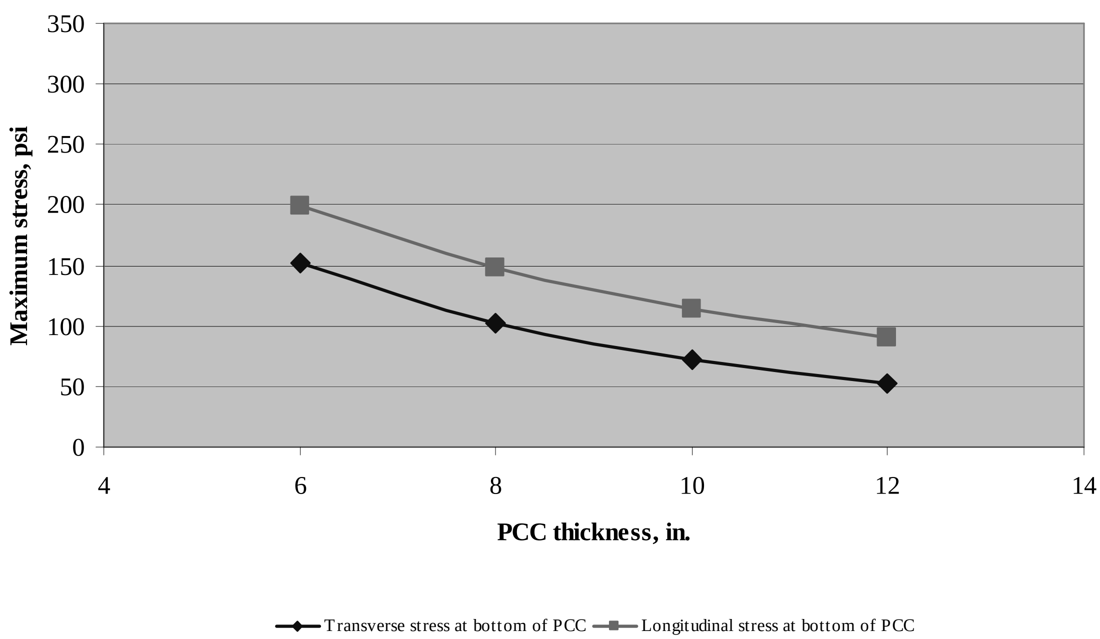


Figure E11-4: Relationship Between Stresses and PCC Thickness

Example 12:
Single Axle Edge Loading with Various Base Thicknesses

Problem Statement

Determine maximum stresses at the bottom of the PCC slab for the pavement system and loading condition in Example 8 considering base thickness = 4, 10, 16, 20, 26 in.

Given

Base thickness	=	4, 10, 16, 20, 26	in.

Problem Illustration

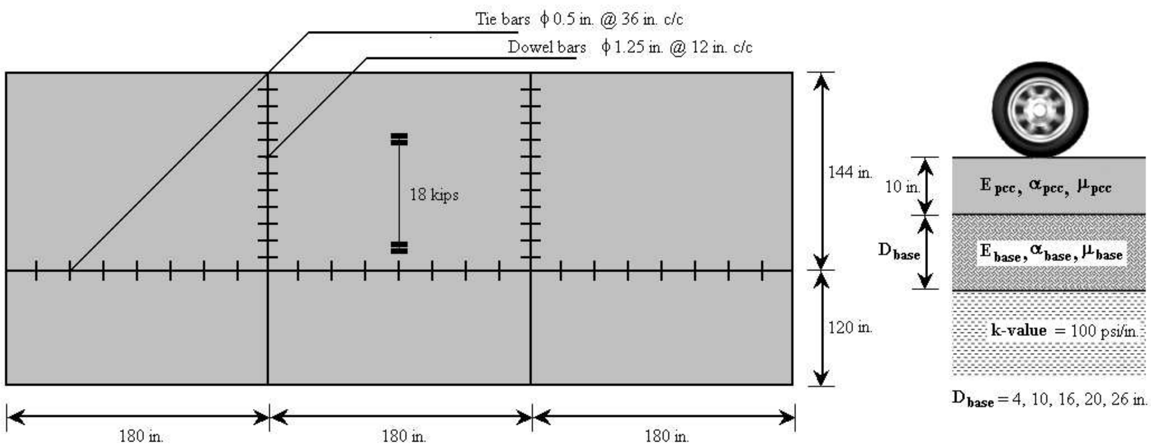


Figure E12-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 8.

Layers Module

(see Figures E12-2 and E12-3)

Step 1: Click **Layers** to open the layers panel.

Step 2: On the layers panel, enter the inputs as identified in the problem statement for the PCC layer.

Step 3: Click **Add Layer** to open the layer panel, enter **2** in the **Layer number to add** field, and then click **OK**.

Step 4: On the layers panel, select the **Layer 2** tab, and then type the inputs as identified in the problem statement for the base layer.

Step 5: Select **Batch** and then click **Edit Batch** to open the layer 2 properties panel (see Figure E12-2).

Step 6: Click **Insert** three times to add three additional cases, and then enter the base thicknesses as identified in the problem statement (see Figure E12-3).

Step 7: Click **OK** to close the layer 2 properties panel, and then click **OK** to close the layers panel.

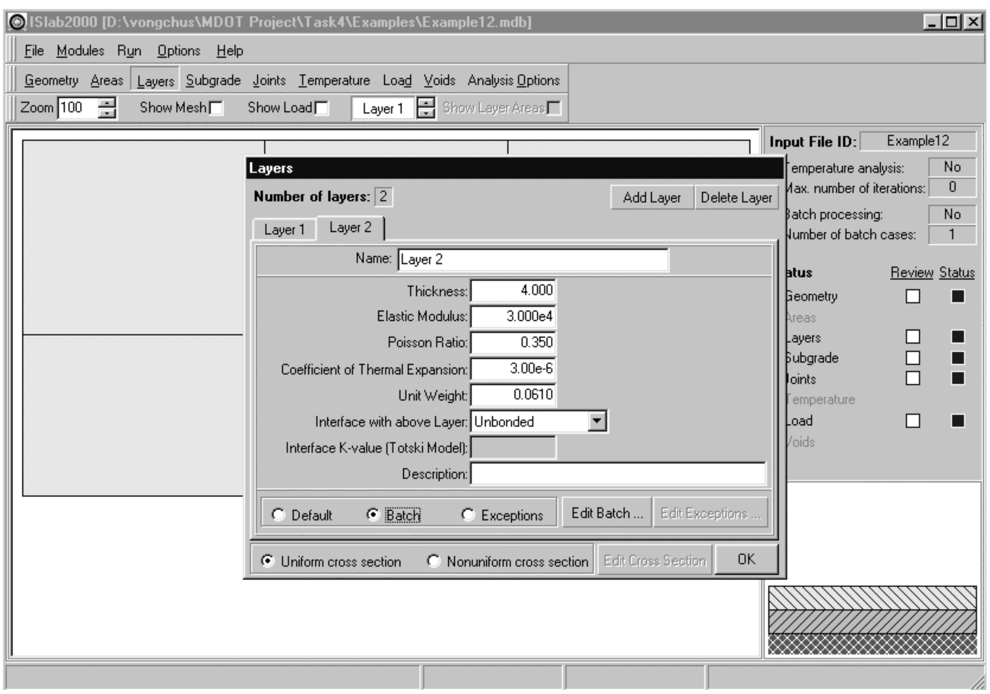


Figure E12-2: Edit Inputs for the Layers Module

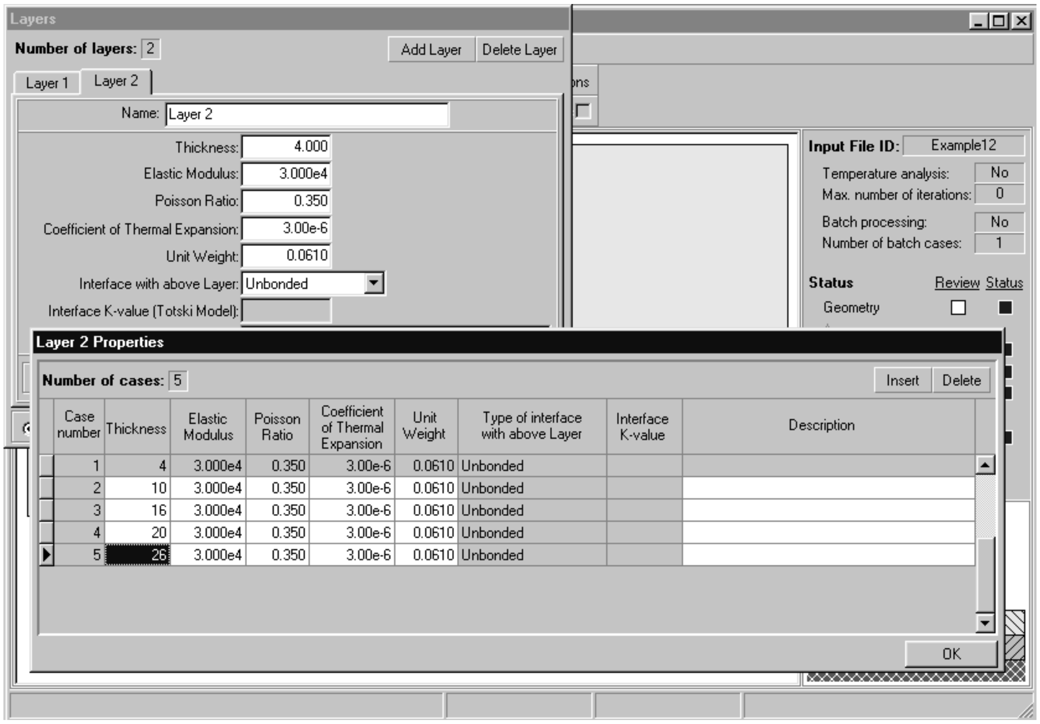


Figure E12-3 Edit Inputs for the Layers Module (continued)

Subgrade Module

Use this module from Example 8.

Joints Module

Use this module from Example 8.

Load Module

Use this module from Example 8.

Temperature Module

This module is not required for this problem.

Analysis Options Module

Use this module from Example 4.

The main panel should display the pavement structure, loading condition, and meshing as shown in Example 8, Figure E8-12.

Analysis Results

Base thickness, in.	Stress at the bottom of the PCC, psi	
	Transverse	Longitudinal
4	74.4	117.4
10	73.9	116.7
16	72.1	114.5
20	70.0	111.8
26	65.3	105.7

Table E12-1: Analysis Results

NOTE
Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Figure E12-4 illustrates relationship between maximum stresses and base thickness.

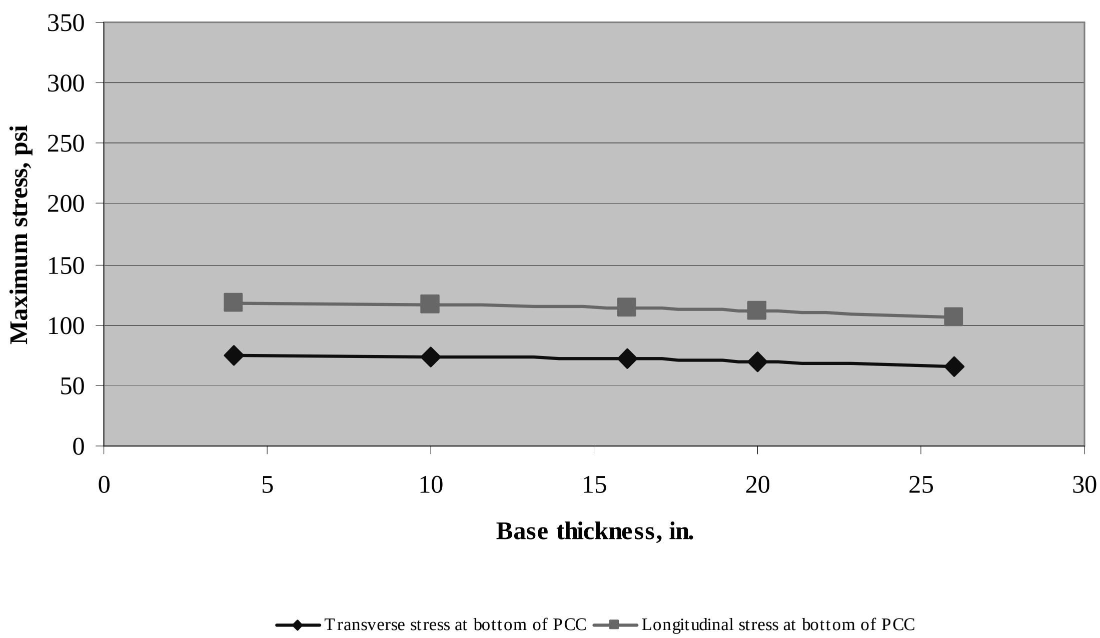


Figure E12-4: Relationship Between Stresses and Temperature Differentials

Example 13:
Single Axle Edge Loading with Various k-values

Problem Statement

Determine maximum stresses at the bottom of the PCC slab for the pavement system and loading condition in Example 8 considering modulus of subgrade reaction, k-value, of 30, 65, 100, 150, 200 psi/in.

Given

k-value = 30, 65, 100, 150, 200 psi/in.

Problem Illustration

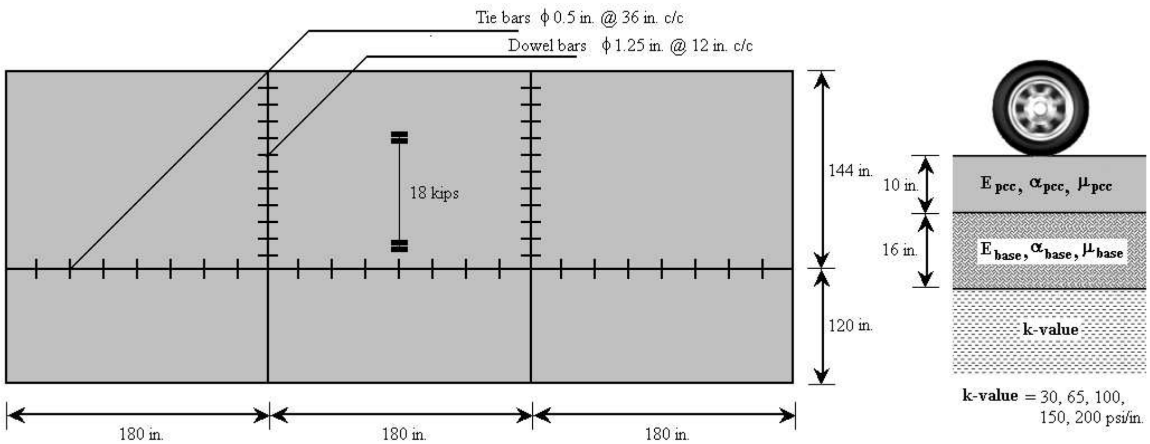


Figure E13-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 8.

Layers Module

Use this module from Example 8.

Subgrade Module

(see Figures E13-2 and E13-3)

Step 1: Click **Layers** to open the layers panel.

Step 2: On the layers panel, enter the first input as identified in the problem statement.

Step 3: On the layers panel, select **Batch**, and then click **Edit Batch** to open the subgrade properties panel (see Figure E13-3).

Step 4: On the subgrade properties panel, click **Insert** four times to add four additional cases, and then type the k-value for each case as identified in the problem statement.

Step 5: Click **OK** to close the subgrade properties panel, and then click **OK** to close the Subgrade panel.

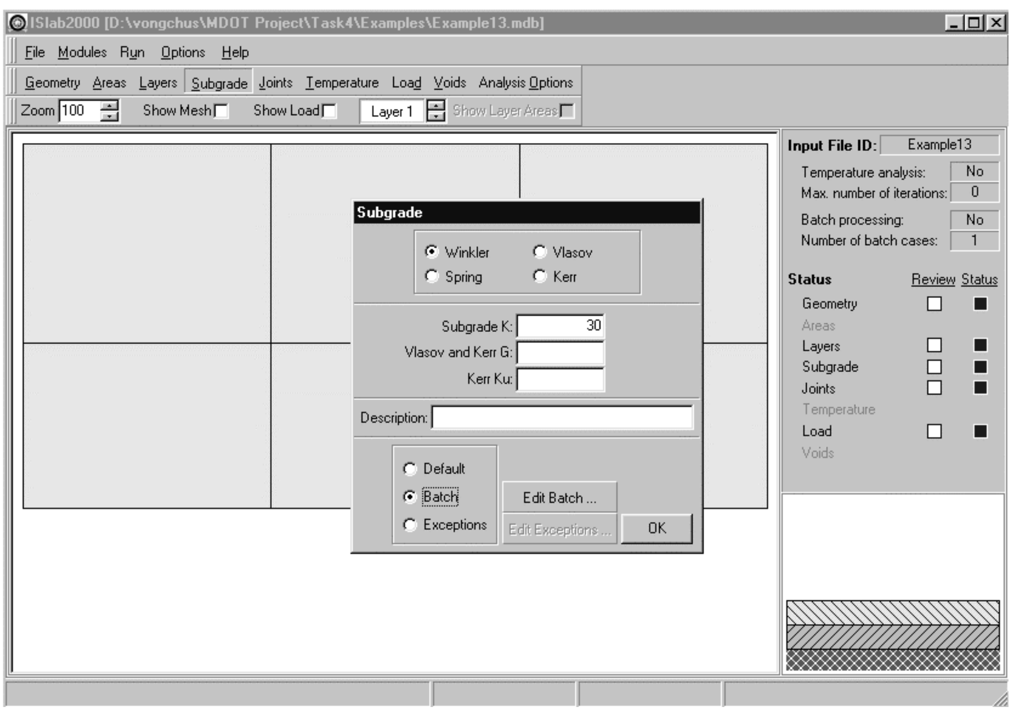


Figure E13-2: Edit Inputs for the Subgrade Module

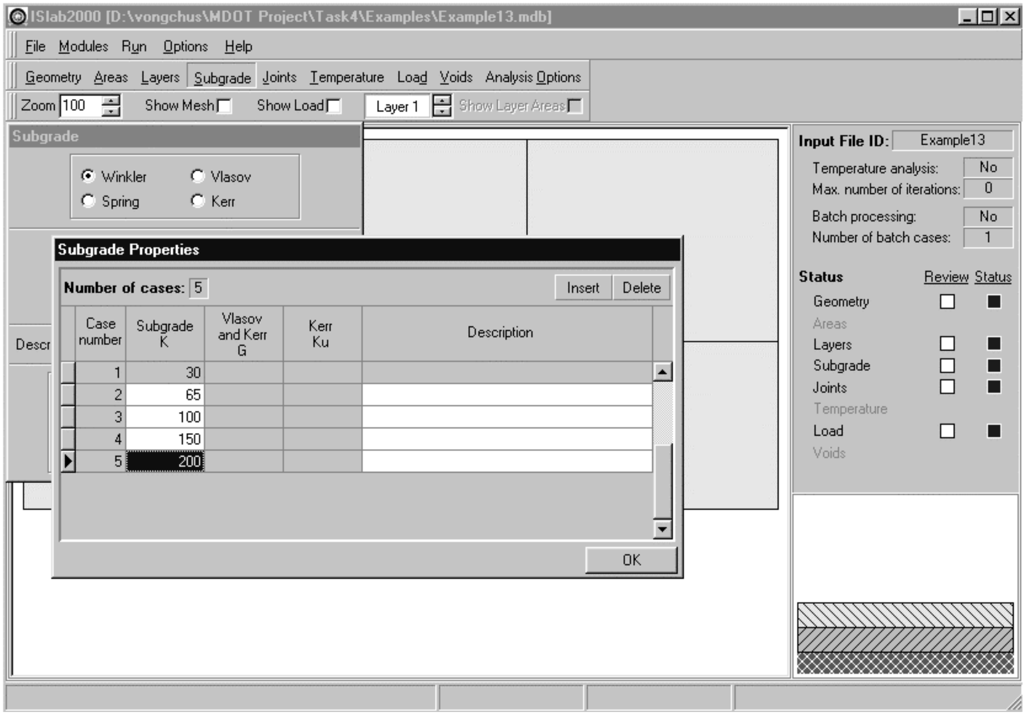


Figure E13-3: Edit Inputs for the Subgrade Module (continued)

Joints Module

Use this module from Example 8.

Load Module

Use this module from Example 8.

Temperature Module

This module is not required for this problem.

Analysis Options Module

Use this module from Example 4.

The main panel should display the pavement structure, loading condition, and meshing as shown in Example 8, Figure E8-12.

Analysis Results

k-value, psi/in.	Stress at the bottom of the PCC, psi	
	Transverse	Longitudinal
30	77.6	146.6
65	74.5	126.3
100	72.1	114.5
150	69.4	103.7
200	67.2	96.5

Table E13-1: Analysis Results

NOTE
Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Figure E13-4 illustrates relationship between maximum stresses and modulus of subgrade reaction.

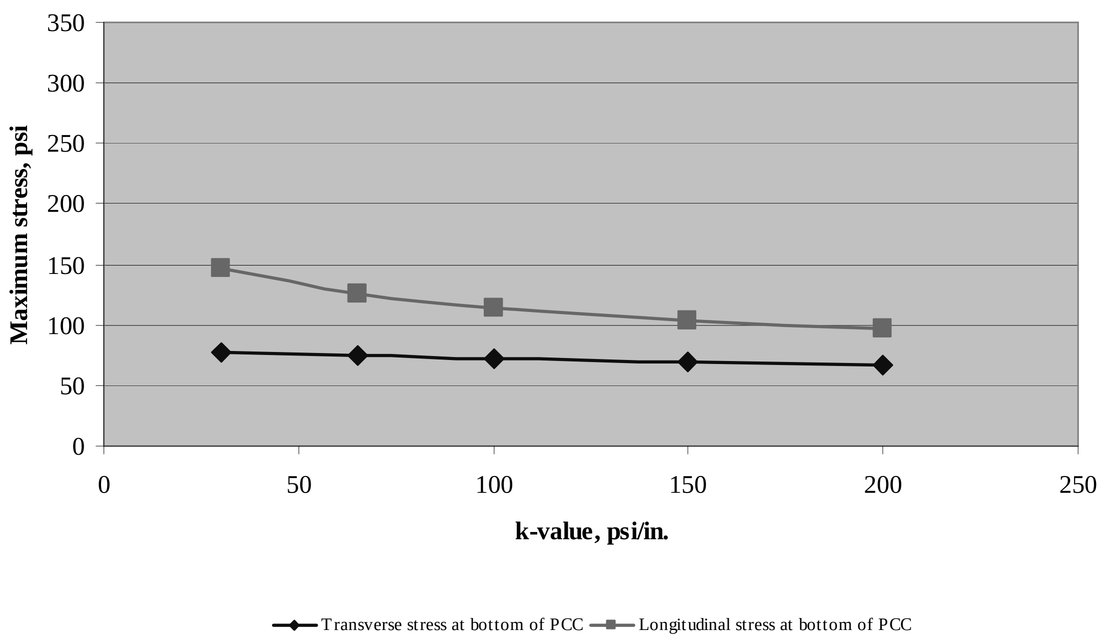


Figure E13-4: Relationship Between Stresses and Modulus of Subgrade Reaction

Example 14:
Single Axle Edge Loading with Various PCC Elastic Moduli

Problem Statement

Determine maximum stresses at the bottom of the PCC slab for the pavement system and loading condition in Example 8 considering PCC elastic modulus, E_{pcc}, of 3, 4, 5, 6x10^6 psi

Given

PCC elastic modulus, E_{pcc} = 3, 4, 5, 6 x 10^6 psi

Problem Illustration

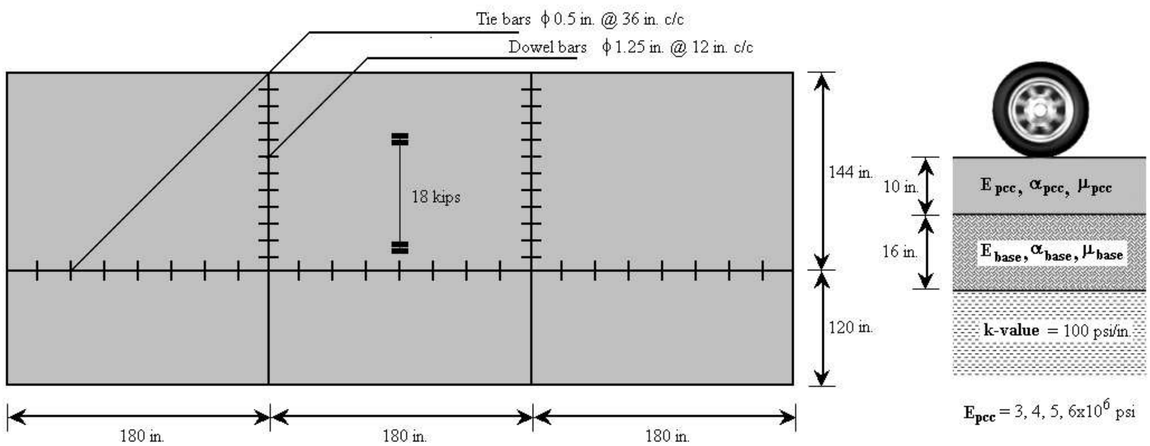


Figure E14-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 8.

Layers Module

(see Figures E14-2 and E14-3)

Step 1: Click **Layers** to open the layers panel.

Step 2: On the layers panel, enter the inputs as identified in the problem statement for the PCC layer.

Step 3: Click **Add Layer** to open the add layer panel, enter **2** in the **Layer number to add** field, and then click **OK** to close the add layer panel and add the layer.

Step 4: On the layers panel, select the **Layer 2** tab, and then type the inputs as identified in the problem statement for the base layer.

Step 5: On the layers panel, select the **Layer 1** tab, select **Batch**, and then click **Edit Batch** to open the layer 1 properties panel (see Figure E14-2).

Step 6: On the layer 1 properties panel, click **Insert** three times to add three additional cases, and then enter the PCC elastic modulus as identified in the problem statement (see Figure E14-3).

Step 7: Click **OK** to close the layer 1 properties panel, and then click **OK** to close the layers panel.

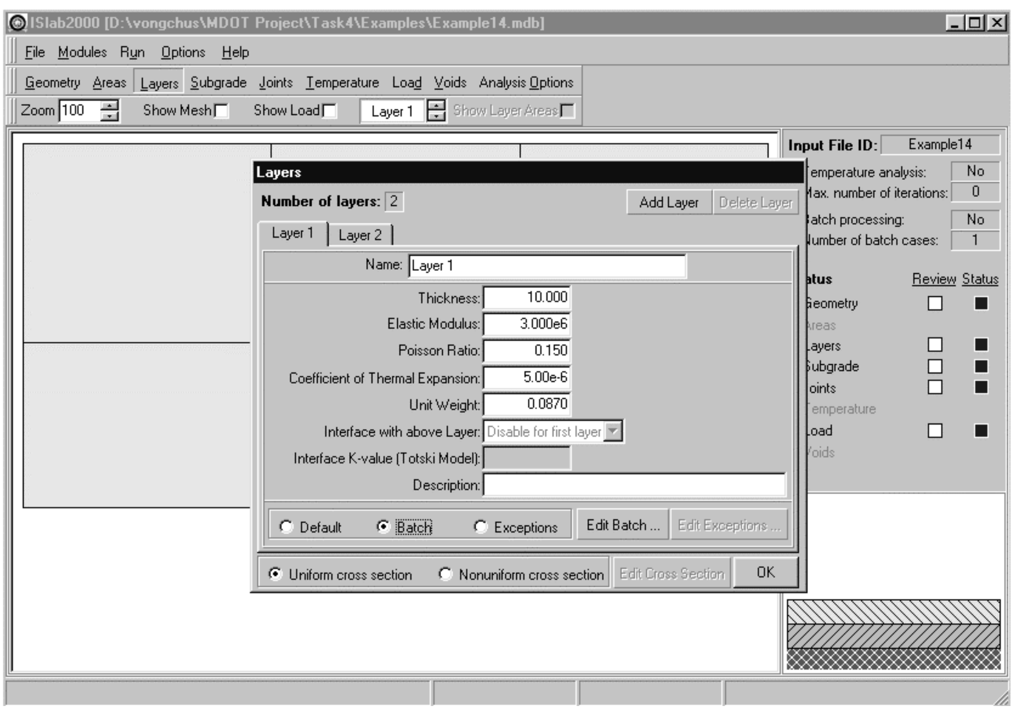


Figure E14-2: Edit Inputs for the Layers Module

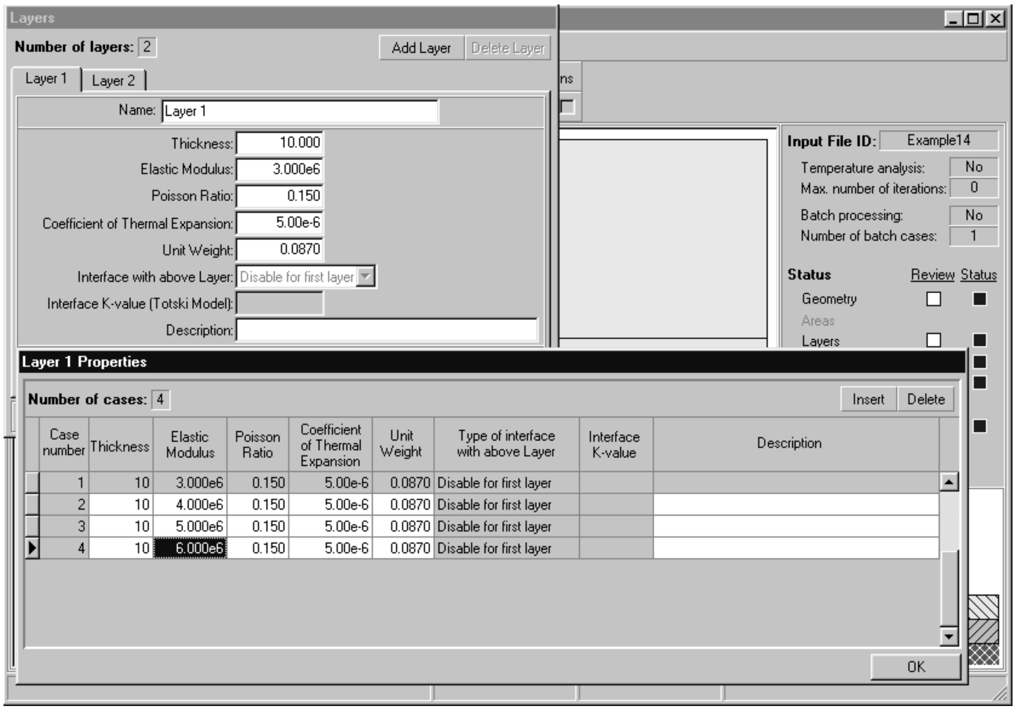


Figure E14-3: Edit Inputs for the Layers Module (continued)

Subgrade Module

Use this module from Example 8.

Joints Module

Use this module from Example 8.

Load Module

Use this module from Example 8.

Temperature Module

This module is not required for this problem.

Analysis Options Module

Use this module from Example 4.

The main panel should display the pavement structure, loading condition, and meshing as shown in Example 8, Figure E8-12.

Analysis Results

E_{pcc}, x10^6 psi	Stress at the bottom of the PCC, psi	
	Transverse	Longitudinal
3	69.5	105.8
4	72.1	114.5
5	73.9	121.2
6	75.1	126.7

Table E14-1: Analysis Results

NOTE

Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Figure E14-4 illustrates relationship between maximum stresses and PCC elastic modulus.

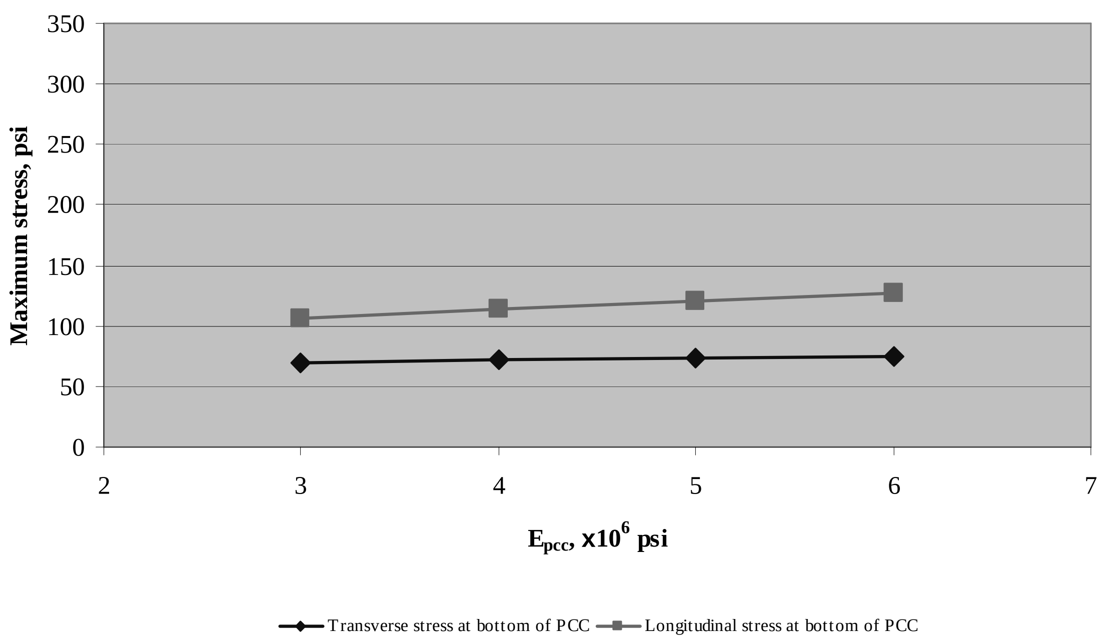


Figure E14-9: Relationship Between Stresses and PCC Elastic Modulus

Example 15:
Single Axle Edge Loading with Various Base Types

Problem Statement

Determine maximum stresses at the bottom of the PCC slab for the pavement system and loading condition in Example 8 considering three different base types: dense-graded aggregate base (DAGB), permeable asphalt-treated base (PATB), lean concrete base (LCB)

Given

E_{DAGB} = 3×10^4 psi

E_{PATB} = 3×10^5 psi

E_{LCB} = 2×10^6 psi

μ_{DAGB} = 0.35

μ_{PATB} = 0.35

μ_{LCB} = 0.2

Problem Illustration

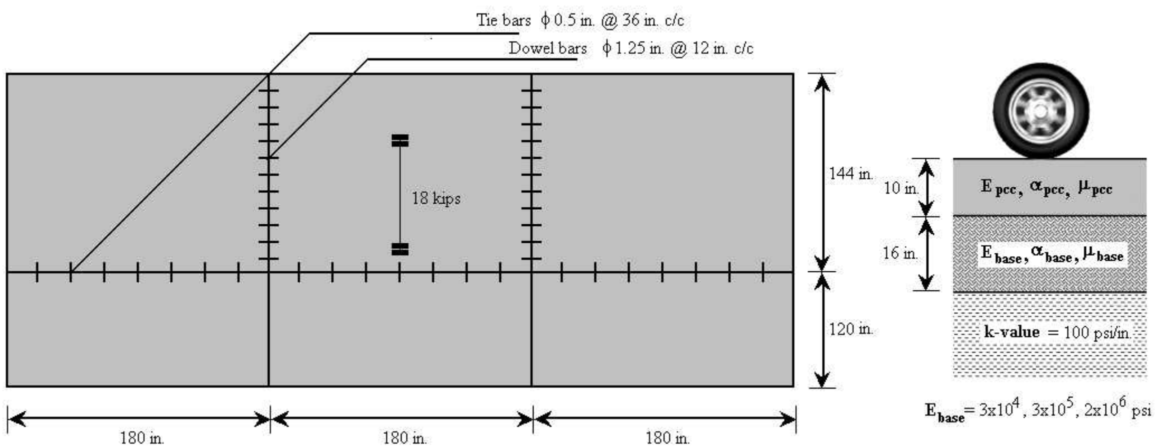


Figure E15-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 8.

Layers Module

(see Figures E15-2 and E15-3)

Step 1: Click **Layers** to open the layers panel.

Step 2: On the layers panel, enter the inputs as identified in the problem statement for the PCC layer.

Step 3: Click **Add Layer** to open the add layer panel, enter **2** in the **Layer number to add** field, and then click **OK** to close the add layer panel.

Step 4: On the layers panel, select the **Layer 2** tab, and then enter the inputs as identified in the problem statement for the base layer.

Step 5: Select **Batch**, and then click **Edit Batch** to open the layer 2 properties panel (see Figure E15-2).

Step 6: On the layer 2 properties panel, click **Insert** two times to add two additional cases, and then type the base elastic modulus and Poisson's ratio as identified in the problem statement (see Figure E15-3).

Step 7: Click **OK** to close the layer 2 properties panel, and then click **OK** to close the layers panel.

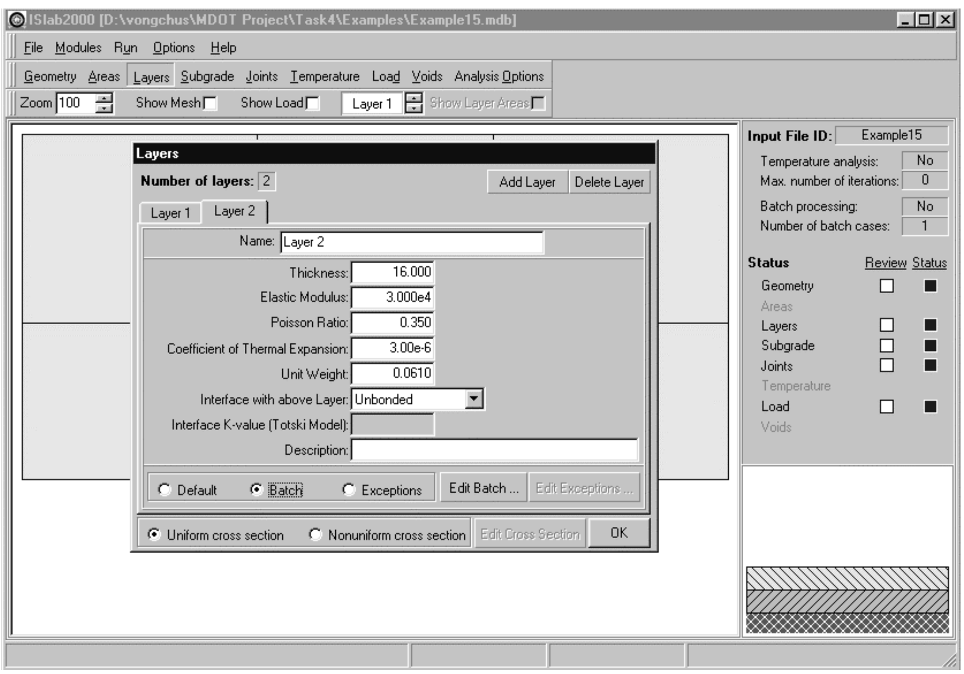


Figure E15-2: Edit Inputs for the Layers Module

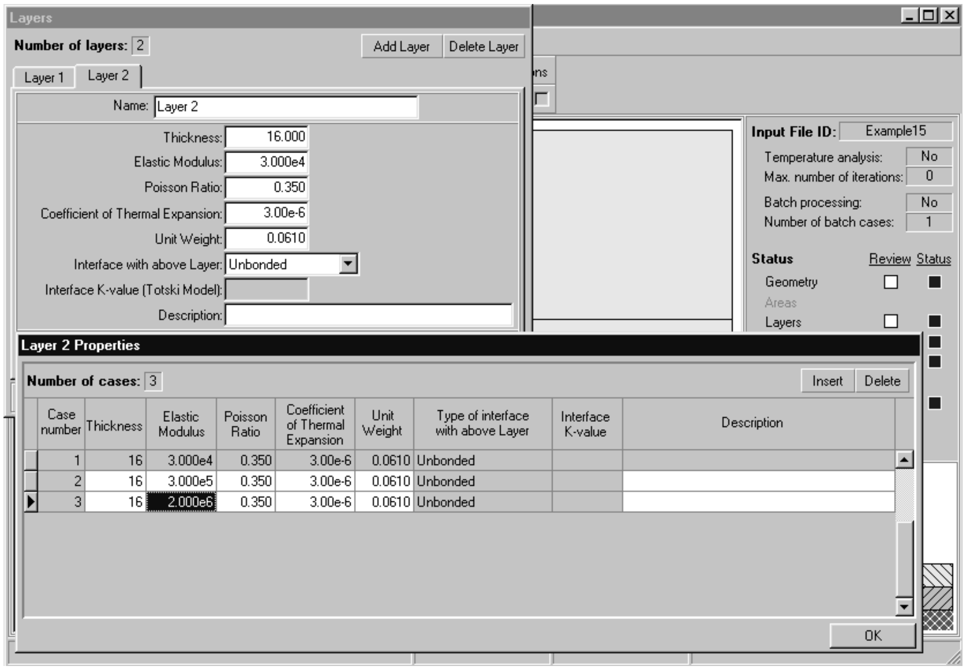


Figure E15-3 Edit Inputs for the Layers Module (continued)

Subgrade Module

Use this module from Example 8.

Joints Module

Use this module from Example 8.

Load Module

Use this module from Example 8.

Temperature Module

This module is not required for this problem.

Analysis Options Module

Use this module from Example 4.

The main panel should display the pavement structure, loading condition, and meshing as shown in Example 8, Figure E8-12.

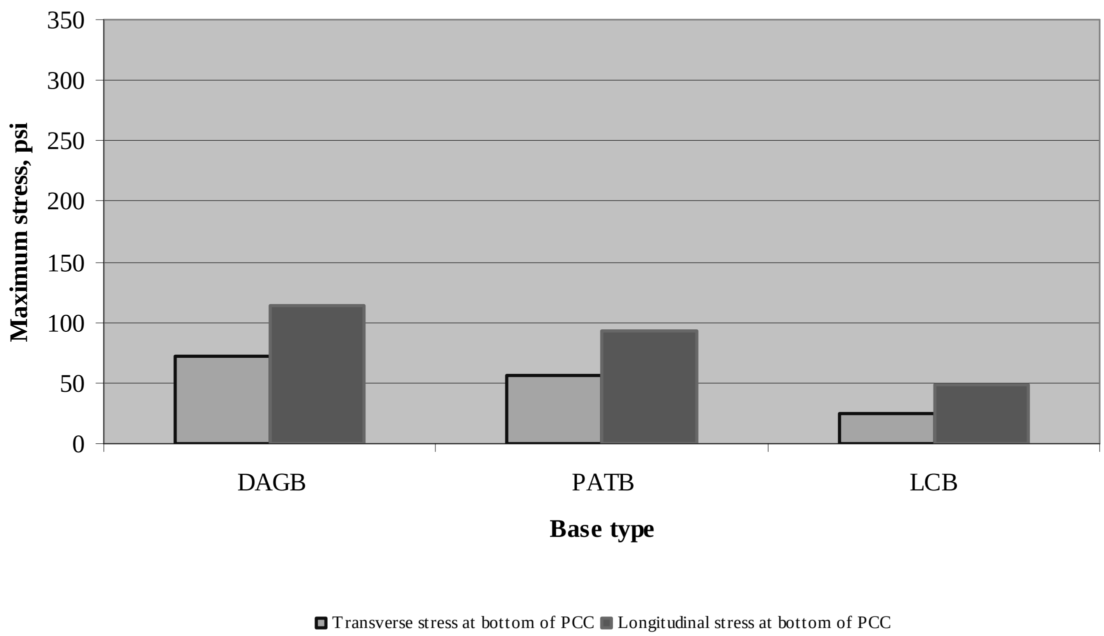
Analysis Results

Base type	Stress at the bottom of the PCC, psi	
	Transverse	Longitudinal
DAGB	72.1	114.5
PATB	56.0	93.6
LCB	25.4	48.1

Table E15-1: Analysis Results

NOTE
Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Figure E15-4 illustrates relationship between maximum stresses and base type.



E15-4: Relationship Between Stresses and Base Type

Example 16:
Repeat Example 13 with a Thermal Gradient

Problem Statement

Repeat Example 13 but at the same time, apply temperature differential, ΔT, of +20 ^oF.

Given

Modulus of subgrade reaction, k-value	=	30, 65, 100, 150, 200	psi/in.
Temperature differential, ΔT	=	+20	^oF.

Problem Illustration

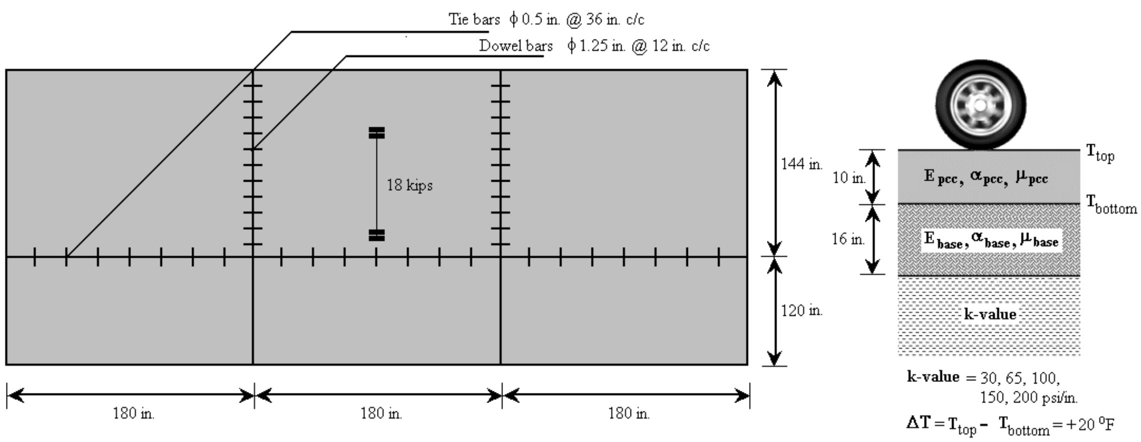


Figure E16-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 8.

Layers Module

Use this module from Example 8.

Subgrade Module

Use this module from Example 13.

Joints Module

Use this module from Example 8.

Load Module

Use this module from Example 8.

Temperature Module

(see Figure E16-2)

Step 1: Click **Temperature** to open the temperature properties panel.

Step 2: Select the **Perform Temperature Analysis** and the Batch check boxes.

Step 3: Enter the temperature differential of the first case in the **Difference** field (20 ^{o}F for this problem).

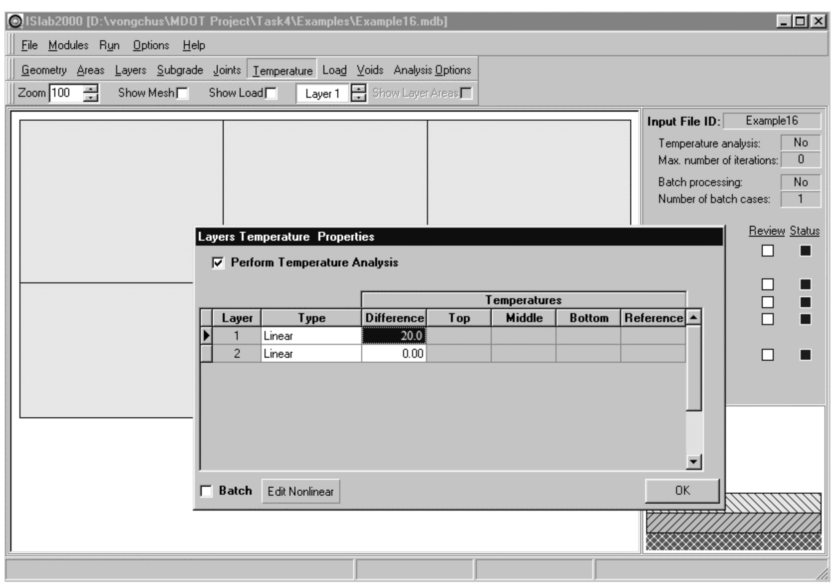


Figure E16-2: Edit Inputs for the Temperature Module

Step 4: Click **OK** to close the layers temperature properties panel.

Analysis Options Module

Use this module from Example 4.

The main panel should display the pavement structure, loading condition, and meshing as shown in Example 8, Figure E8-12.

Analysis Results

k-value, psi/in.	Stress at the bottom of the PCC, psi	
	Transverse	Longitudinal
30	107.7	198.8
65	124.9	211.5
100	139.7	224.5
150	157.3	240.1
200	171.7	252.4

Table E16-1: Analysis Results

NOTE

Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Figure E16-3 illustrates relationship between maximum stresses and modulus of subgrade reaction.

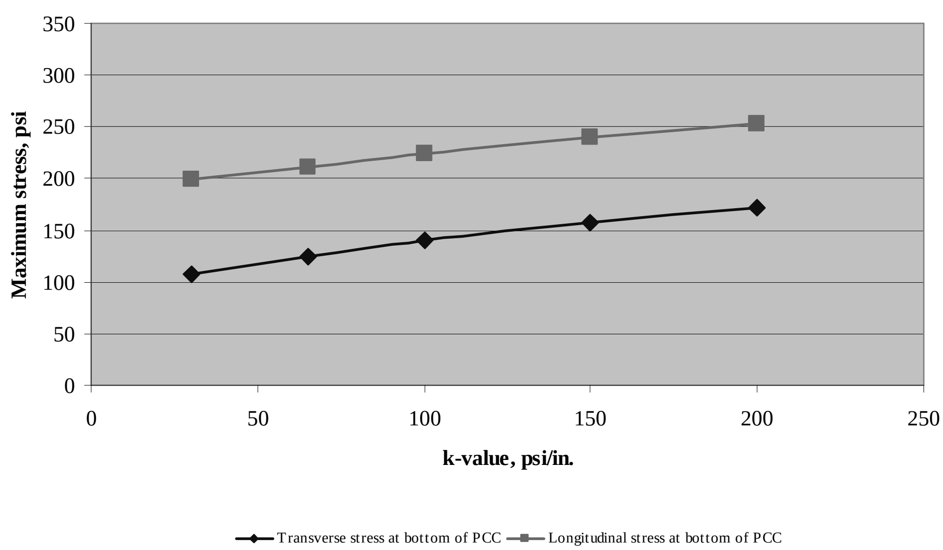


Figure E16-3: Relationship between stresses and modulus of subgrade reaction

Example 17:
Repeat Example 14 with a Thermal Gradient

Problem Statement

Repeat Example 14 but at the same time, apply temperature differential, ΔT, of +20 °F.

Given

PCC elastic modulus, E_{pcc}	=	3, 4, 5, 6 x 10^6	psi
Temperature differential, ΔT	=	+20	°F.

Problem Illustration

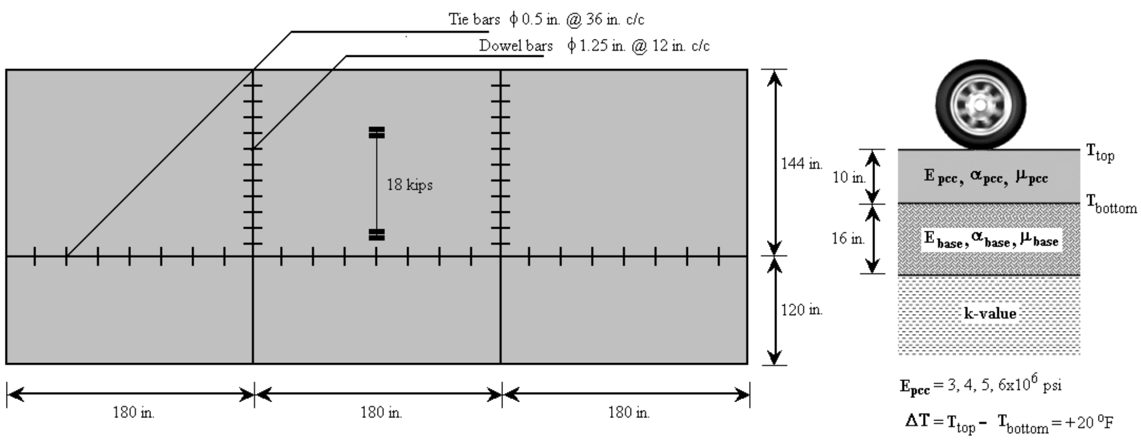


Figure E17-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 8.

Layers Module

Use this module from Example 14.

Subgrade Module

Use this module from Example 8.

Joints Module

Use this module from Example 8.

Load Module

Use this module from Example 8.

Temperature Module

Use this module from Example 16.

Analysis Options Module

Use this module from Example 4.

The main panel should display the pavement structure, loading condition, and meshing as shown in Example 8, Figure E8-12.

Analysis Results

E_{pcc}, x10^6 psi	Stress at the bottom of the PCC, psi	
	Transverse	Longitudinal
3	131.6	203.0
4	139.7	224.5
5	145.2	240.7
6	149.2	253.5

Table E17-1: Analysis Results

NOTE
Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Figure E17-2 illustrates relationship between maximum stresses and PCC elastic modulus.

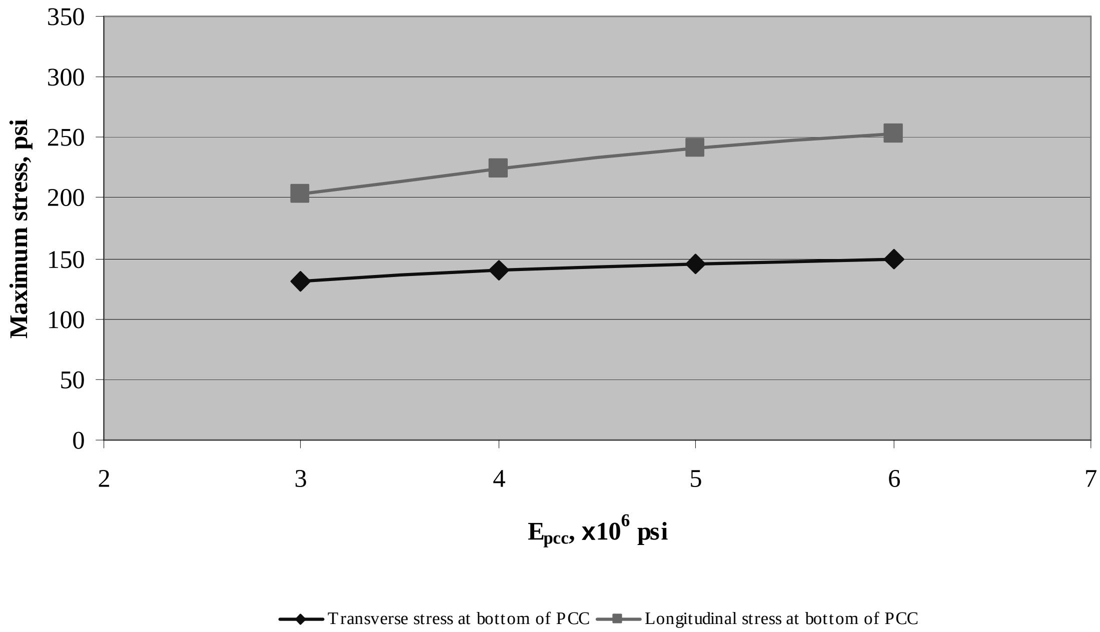


Figure E17-2: Relationship Between Stresses and PCC Elastic Modulus

Example 18:
Repeat Example 15 with a Thermal Gradient

Problem Statement

Repeat Example 15 but at the same time, apply temperature differential, ΔT, of +20 ^oF.

Given

E_{DAGB} = 3×10^4 psi

E_{PATB} = 3×10^5 psi

E_{LCB} = 2×10^6 psi

μ_{DAGB} = 0.35

μ_{PATB} = 0.35

μ_{LCB} = 0.2

ΔT = +20 ^oF.

Problem Illustration

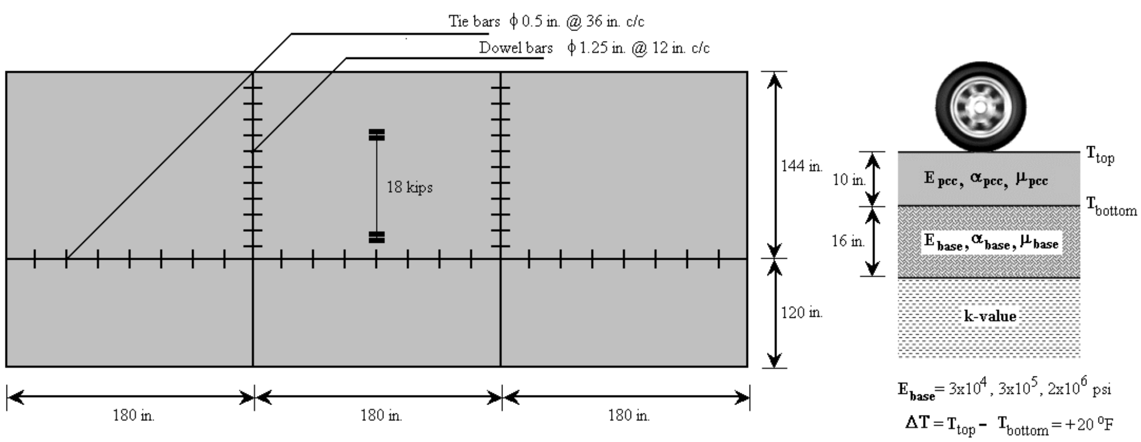


Figure E18-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 8.

Layers Module

Use this module from Example 15.

Subgrade Module

Use this module from Example 8.

Joints Module

Use this module from Example 8.

Load Module

Use this module from Example 8.

Temperature Module

Use this module from Example 16.

Analysis Options Module

Use this module from Example 4.

The main panel should display the pavement structure, loading condition, and meshing as shown in Example 8, Figure E8-12.

Analysis Results

Base type	Stress at the bottom of the PCC, psi	
	Transverse	Longitudinal
DAGB	139.7	224.5
PATB	157.5	223.7
LCB	194.0	223.9

Table E18-1: Analysis Results

NOTE
Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Figure E18-3 illustrates relationship between maximum stresses and base type.

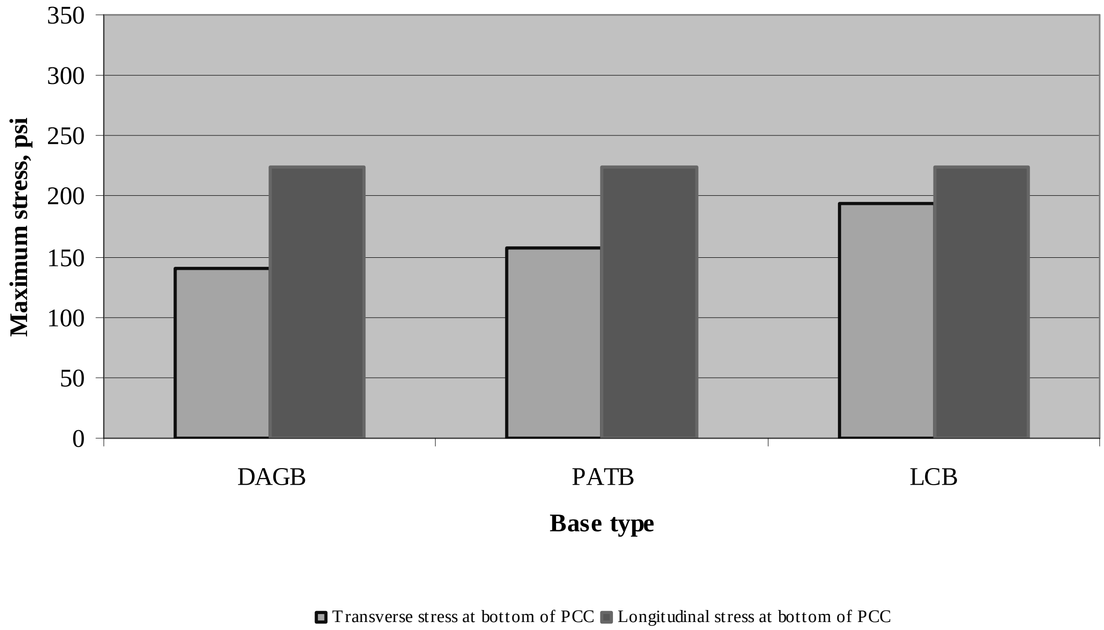


Figure E18-3: Relationship Between Stresses and Base Type

Example 19:
Single Axle Edge Loading with Various Load Levels

Problem Statement

Repeat Example 8 but consider several axle weight levels for single axle: 10, 15, 18, 21, 25 kips

Given

Loading configuration	=	single axle	
Axle weight	=	10, 15, 18, 21, 25	kips

Problem Illustration

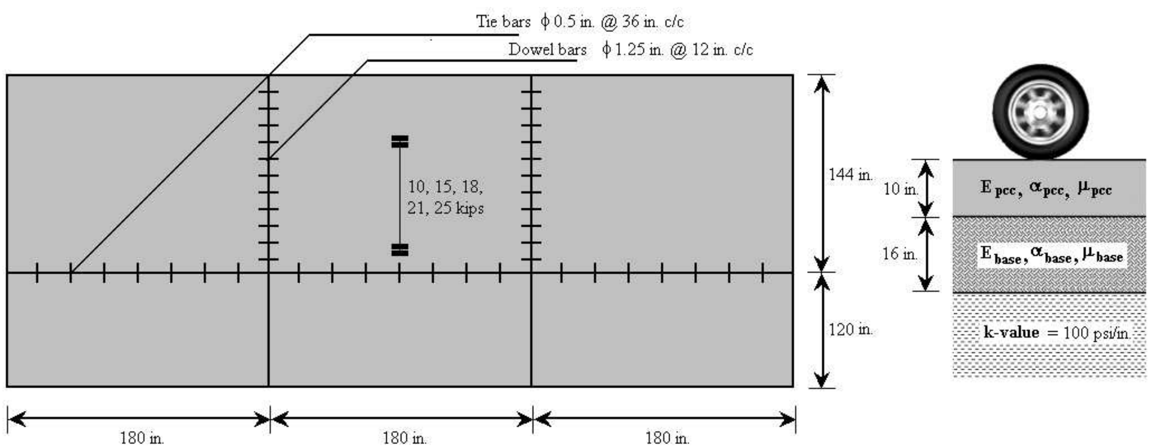


Figure E19-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 8.

Layers Module

Use this module from Example 8.

Subgrade Module

Use this module from Example 8.

Joints Module

Use this module from Example 8.

Load Module

(see Figures E19-2 and E19-3)

Step 1: Follow steps 1 through 10 of Example 8.

Step 2: Enter the load for the first case of single axle (10,000 lbs for this example).

Step 3: Select **Batch** and then click **Edit Batch** to open the batch load panel (see Figure E19-2).

Step 4: Click **Add** four times, and then enter the other four axle weights.

Step 5: Click **OK** to close the batch load panel, and then click **OK** to close the Load panel.

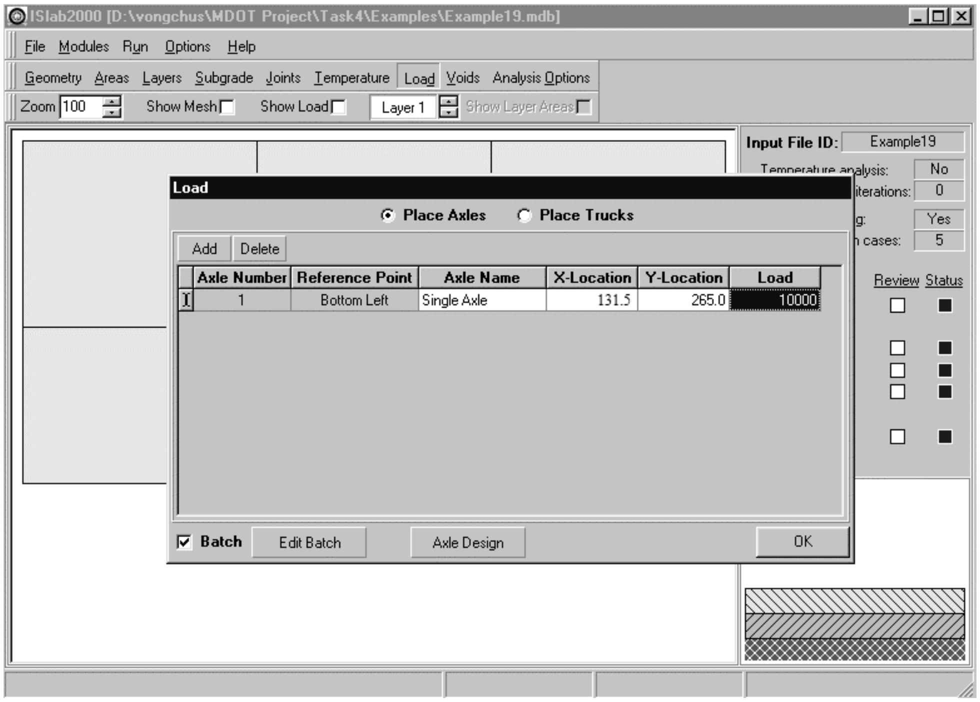


Figure E19-2: Edit Inputs for the Load Module

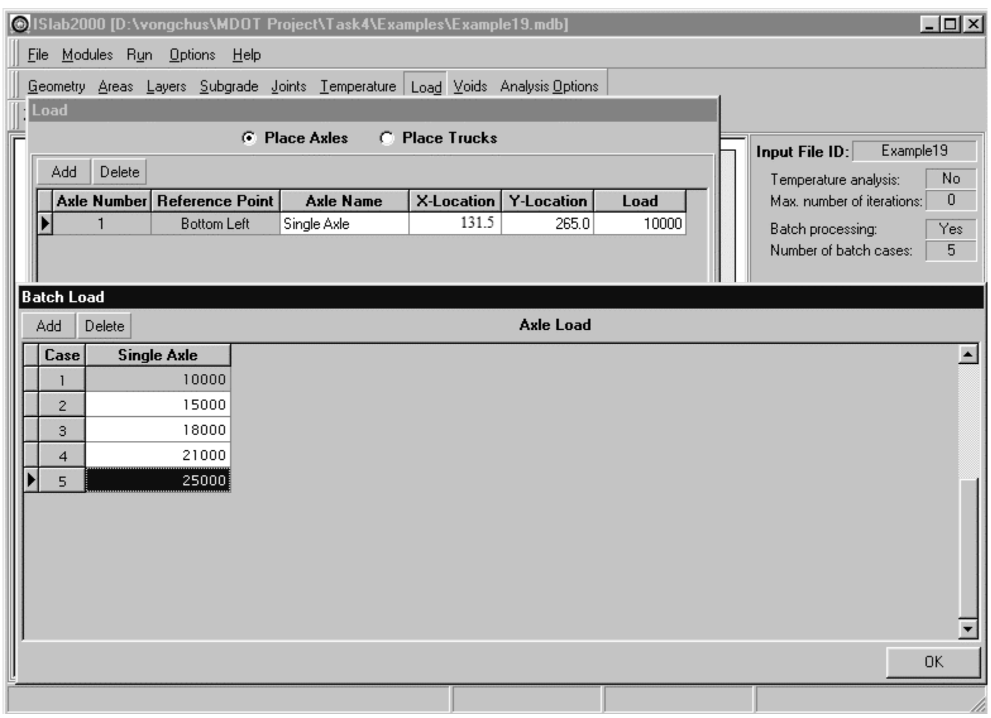


Figure E19-3: Edit Inputs for the Load Module (continued)

Temperature Module

This module is not required for this problem.

Analysis Options Module

Use this module from Example 4.

The main panel should display the pavement structure, loading condition, and meshing as shown in Example 8, Figure E8-12.

Analysis Results

Axle wt., kips	Stress at the bottom of the PCC, psi	
	Transverse	Longitudinal
10	43.6	74.1
15	62.1	101.2
18	72.1	114.5
21	86.1	139.6
25	104.5	172.2

Table E19-1: Analysis Results

NOTE
Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Figure E19-4 illustrates relationship between maximum stresses and axle weight.

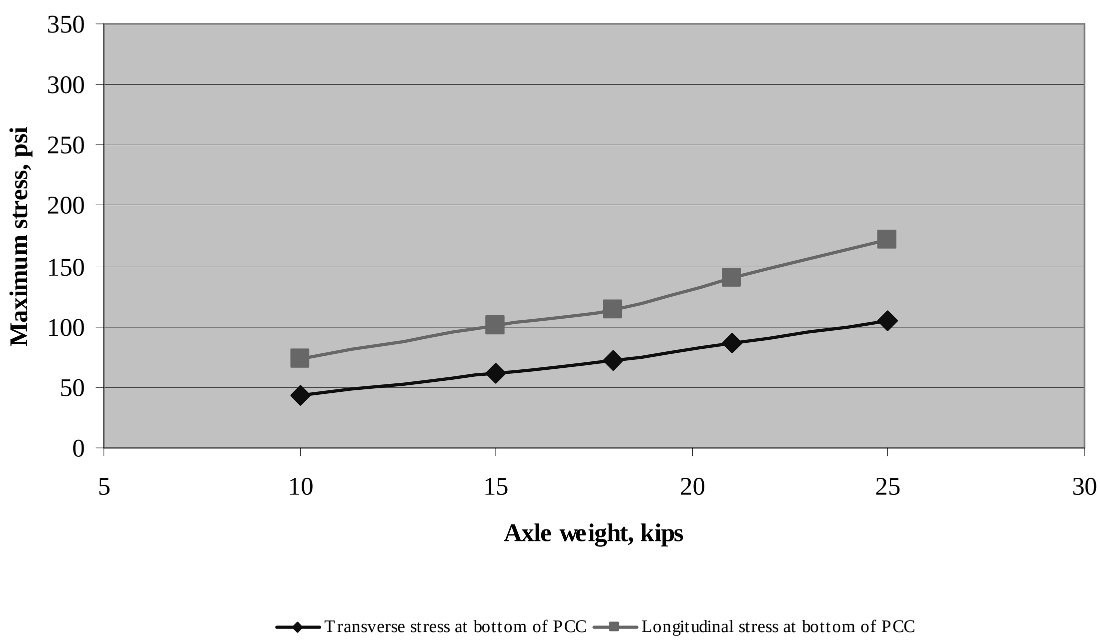


Figure E19-4: Relationship Between Stresses and Axle Weight

Example 20:
Tandem Axle Edge Loading with Various Load Levels

Problem Statement

Repeat Example 8 but consider several axle weight levels for tandem axle: 21, 25, 32, 40 kips

Given

Loading configuration	=	tandem axle	
Axle weight	=	21, 25, 32, 40	kips

Problem Illustration

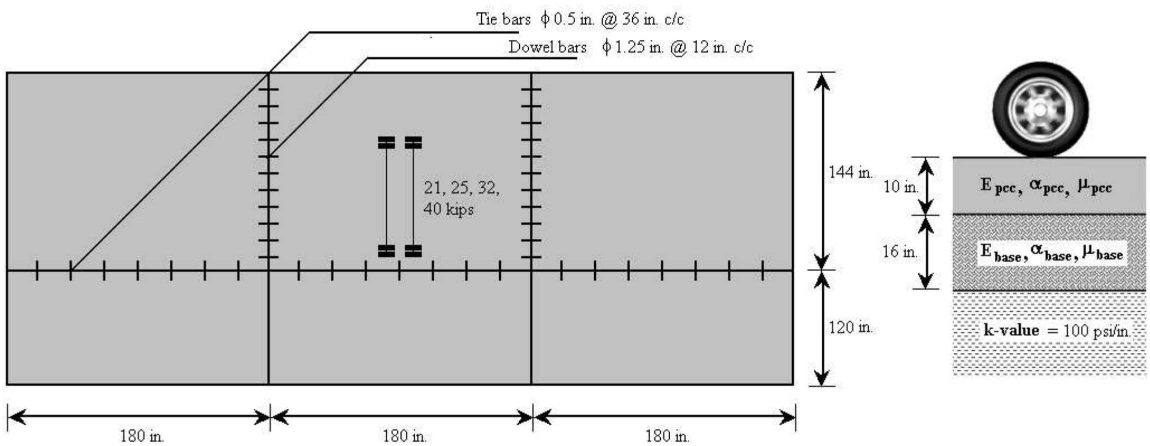


Figure E20-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 8.

Layers Module

Use this module from Example 8.

Subgrade Module

Use this module from Example 8.

Joints Module

Use this module from Example 8.

Load Module

(see Figures E20-2 through E20-4)

Step 1: Click **Load** to open the load panel.

Step 2: Click **Axle Design** to open the axle design panel (see Figure E20-2), and then enter **Tandem Axle** in the **Axle Name** field.

Step 3: Enter the tire pressure in the **Tire Pressure** field. The tire pressure of the wheel load can be computed as shown below (for more detail, see standard configuration of tandem axle):

$$Tire\ Pressure = \frac{Wheel\ Load}{Contact\ Area} = \frac{4{,}000\ lbs}{5\ in. \times 10\ in.} = 80\ psi$$

Step 4: Enter the tire width in the **Tire Width** box (5 in. for this example).

Step 5: Enter wheel spacing information as shown in Figure E20-2.

Step 6: Select **Bottom Left** for the reference point position.

Step 7: Click **OK** to close the axle design panel.

Step 8: On the load panel, click **Add** to add a load (see Figure E20-3).

Step 9: In the **Axle Name** field, select **Tandem Axle**.

Step 10: Enter X-location and Y-location information to locate the wheel load. X-location and Y-location for an edge loading condition can be computed as shown below:

$$X - location = Shoulder\ width + Distance\ dual\ wheel\ center\ to\ shoulder - Distance\ dual\ wheel\ center\ to\ reference\ point$$

$$= 120 + 20 - \left(\frac{5}{2} + \frac{12}{2}\right) = 131.5\ in$$

$$Y - location = Joint\ spacing + \frac{Joint\ spacing}{2} - \frac{wheel\ load\ length}{2} - \frac{wheel\ spacing}{2}$$

$$= 180 + \frac{180}{2} - \frac{10}{2} - \frac{42}{2} = 244\ in$$

Step 11: Enter the load for the first case of tandem axle (21,000 lbs).

Step 12: Select **Batch** and then click **Edit Batch** to open the batch load panel (see Figure E20-4)

Step 13: Click **Add** three times to add three additional tandem axle cases, and then enter the other three axle weights.

Step 14: Click **OK** to close the batch load panel, and then click **OK** to close the load panel.

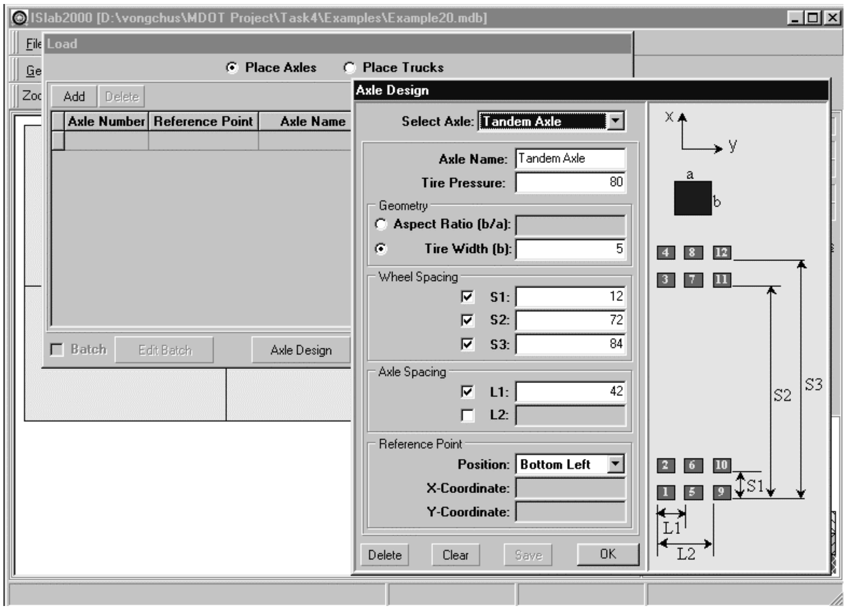


Figure E20-2: Edit Inputs for the Load Module

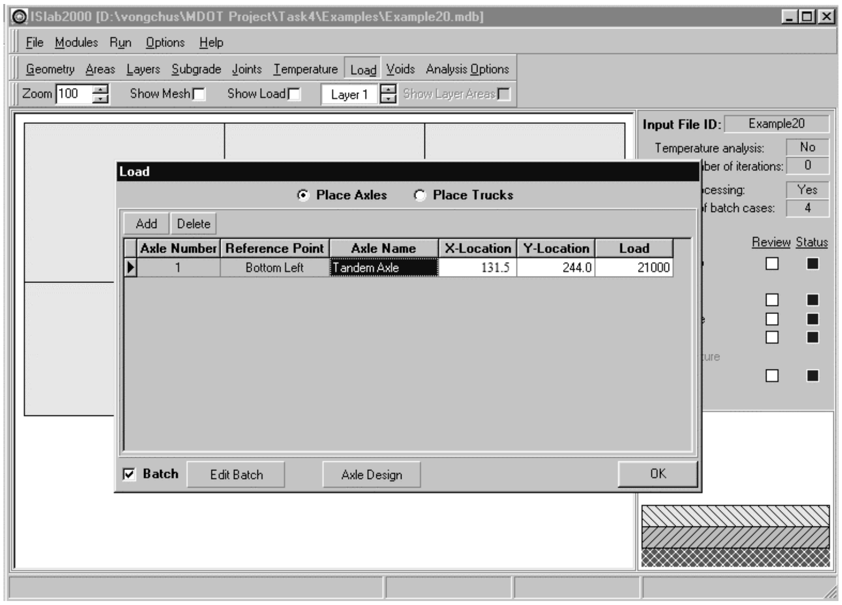


Figure E20-3: Edit Inputs for the Load Module (continued)

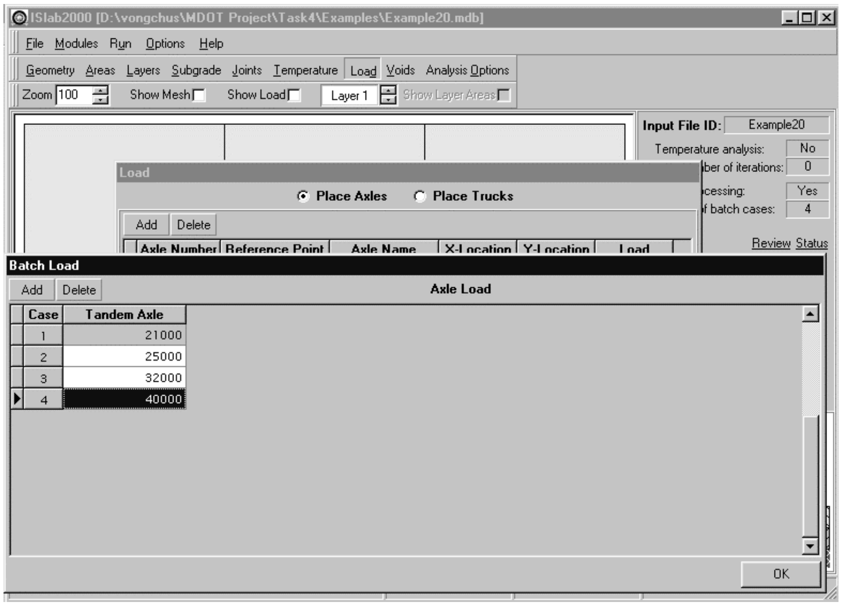


Figure E20-4: Edit Inputs for the Load Module (continued)

Temperature Module

This module is not required for this problem.

Analysis Options Module

Use this module from Example 4.

The main panel should display the pavement structure, loading condition, and meshing as shown in Figure E20-5.

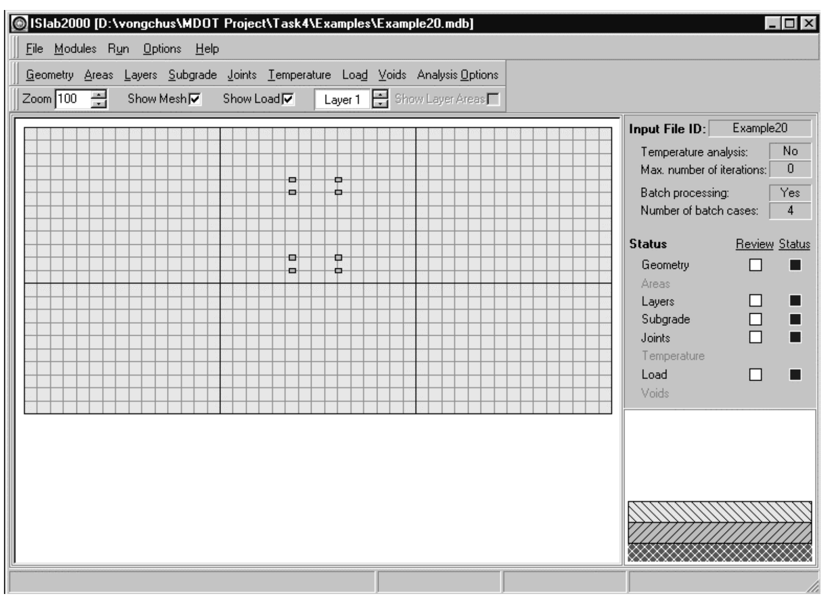


Figure E20-5: Main Panel After the Completion of Inputs

Analysis Results

Axle wt., kips	Stress at the bottom of the PCC, psi	
	Transverse	Longitudinal
21	58.7	91.7
25	69.4	107.2
32	87.3	131.6
40	108.6	164.0

Table E20-1: Analysis Results

NOTE

Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Stress and deflection contours from ISLAB2000 are also available in Figures E20-6 through E20-8.Figure E20-9 illustrates relationship between maximum stresses and axle weight.

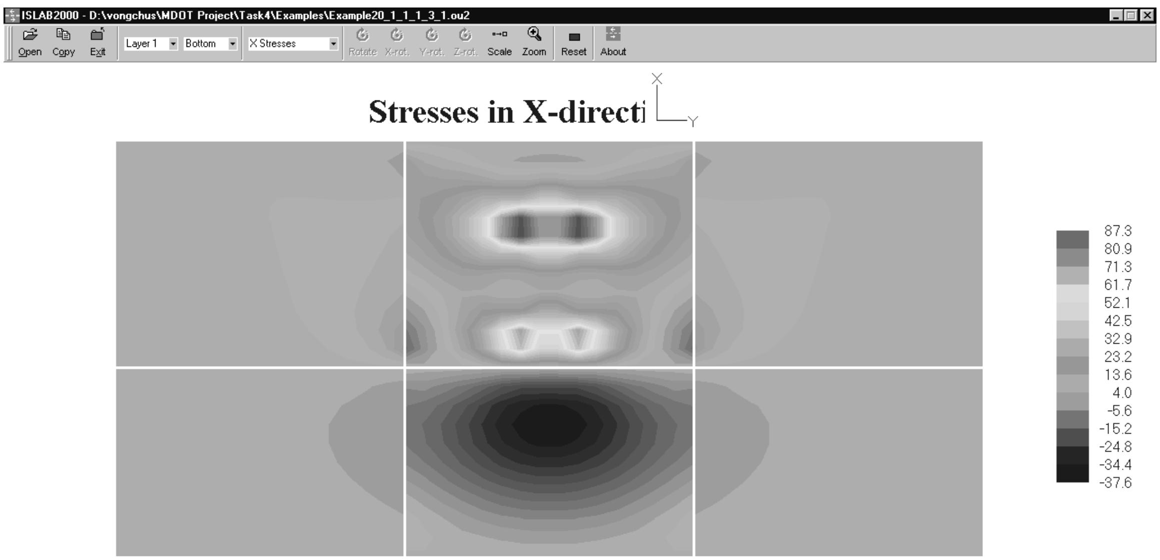


Figure E20-6: Transverse Stress at the Bottom of the PCC Slab, 32-kips Axle Weight

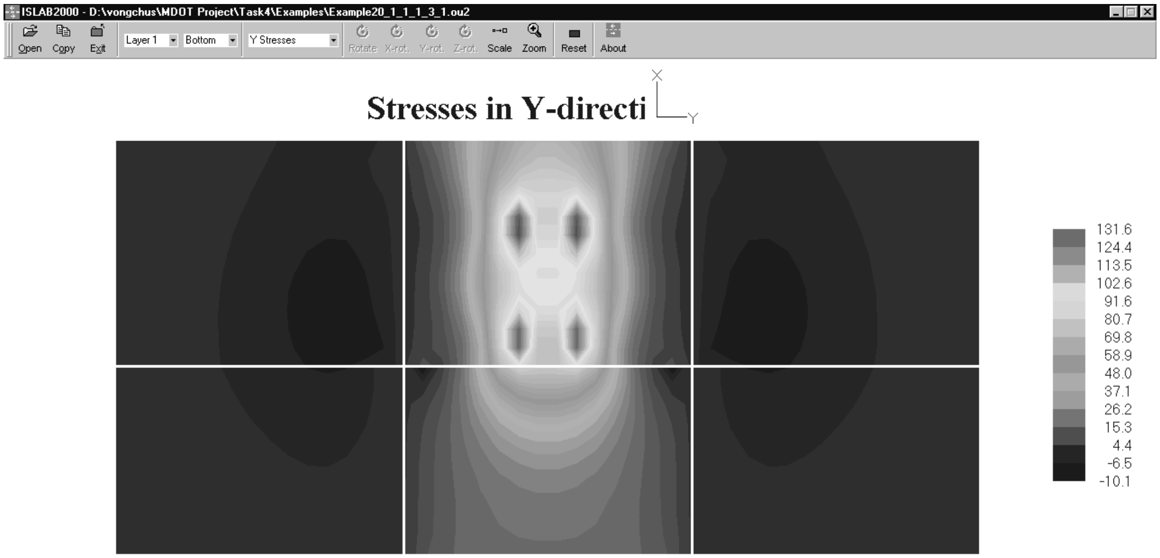


Figure E20-7: Longitudinal Stress at the Bottom of the PCC From ISLAB2000, 32-kips Axle Weight

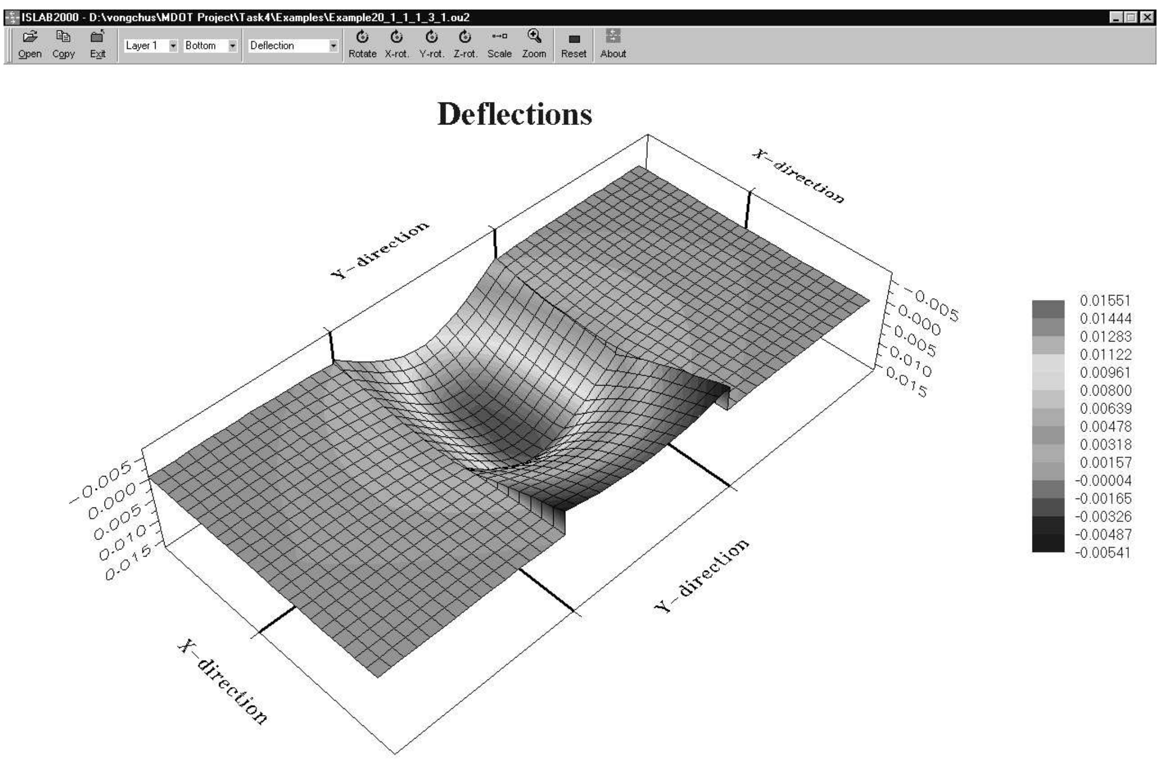


Figure E20-8: Deflection of the PCC slab, 32-kips Axle Weight

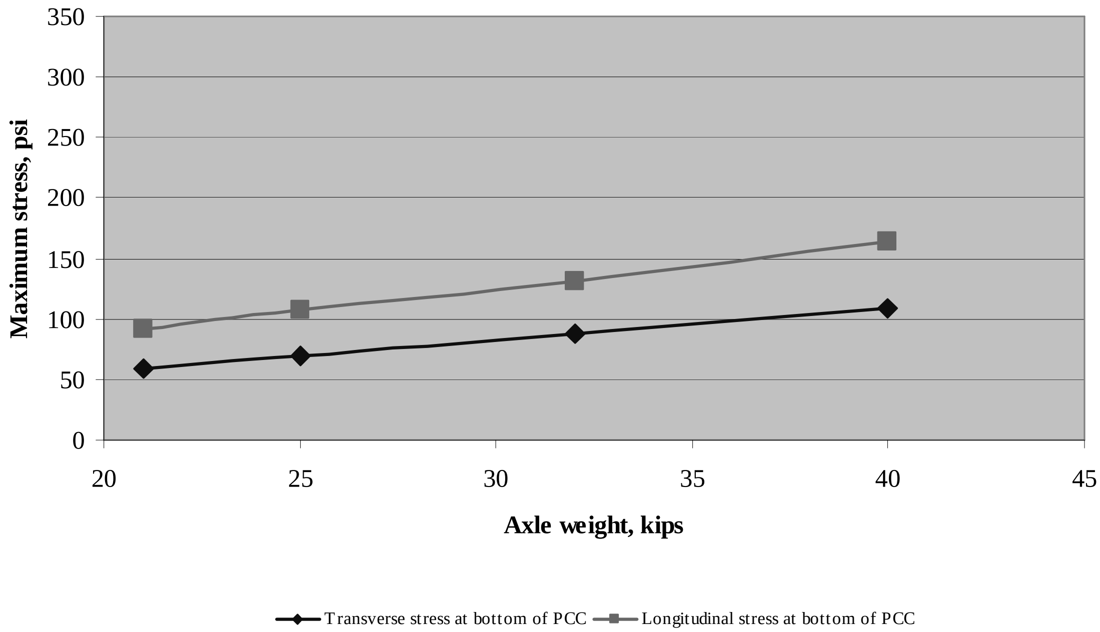


Figure E20-9: Relationship Between Stresses and Axle Weight

Example 21:
Tridem Axle Edge Loading with Various Load Levels

Problem Statement

Repeat Example 8 but consider several axle weight levels for tridem axle: 21, 25, 32, 40 kips. Then, compare the results for 21 and 25 kips loading with the results from Examples 19 and 20.

Given

Loading configuration	=	tridem axle	
Axle weight	=	21, 25, 32, 40	kips

Problem Illustration

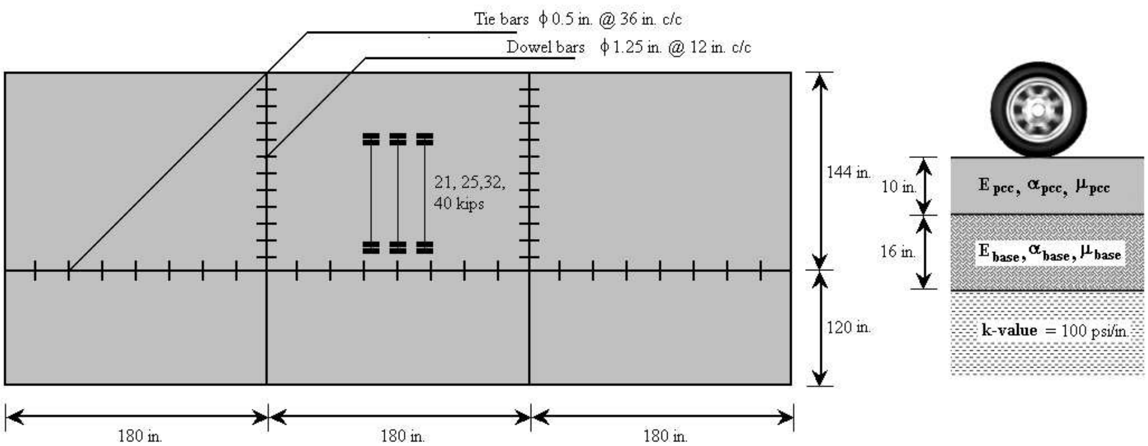


Figure E21-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 8.

Layers Module

Use this module from Example 8.

Subgrade Module

Use this module from Example 8.

Joints Module

Use this module from Example 8.

Load Module

(see Figures E21-2 through E21-4)

Step 1: Click **Load** to open the load panel.

Step 2: On the load panel, click **Axle Design** to open the axle design panel (see Figure E21-2), and then enter **Tridem Axle** in the **Axle Name** field.

Step 3: Enter the tire pressure in the **Tire Pressure** field. The tire pressure of the wheel load can be computed as shown below (for more detail, see standard configuration of tridem axle):

$$Tire\ Pressure = \frac{Wheel\ Load}{Contact\ Area} = \frac{6{,}500\ lbs}{5\ in.\times 10\ in.} = 65\ psi$$

Step 4: Enter the tire width in the **Tire Width** box (5 in. for this example).

Step 5: Enter wheel spacing information as shown in Figure E21-2.

Step 6: Select **Bottom Left** for the reference point position.

Step 7: Click **OK** to close the axle design panel.

Step 8: On the load panel, click **Add** to add additional loads.

Step 9: In the Axle Name box, select **Tridem Axle**.

Step 10: Enter X-location and Y-location information to locate the wheel load. X-location and Y-location for edge loading condition can be computed as shown below:

$$X - location = Shoulder\ width + Distance\ dual\ wheel\ center\ to\ shoulder - Distance\ dual\ wheel\ center\ to\ reference\ point$$

$$= 120 + 20 - \left(\frac{5}{2} + \frac{12}{2}\right) = 131.5\ in$$

$$Y - location = Joint\ spacing + \frac{Joint\ spacing}{2} - \frac{wheel\ load\ length}{2} - wheel\ spacing$$

$$= 180 + \frac{180}{2} - \frac{10}{2} - 42 = 223\ in$$

Step 11: Enter the load for the first case of tridem axle (21,000 lbs).

Step 12: Select **Batch**, and then click **Edit Batch** (see Figure E21-3) to open the batch load panel (see Figure E21-4).

Step 13: Click **Add** three times to add three additional axles, and then enter the other three axle weights.

Step 14: Click **OK** to close the batch load panel, and then click OK to close the load panel.

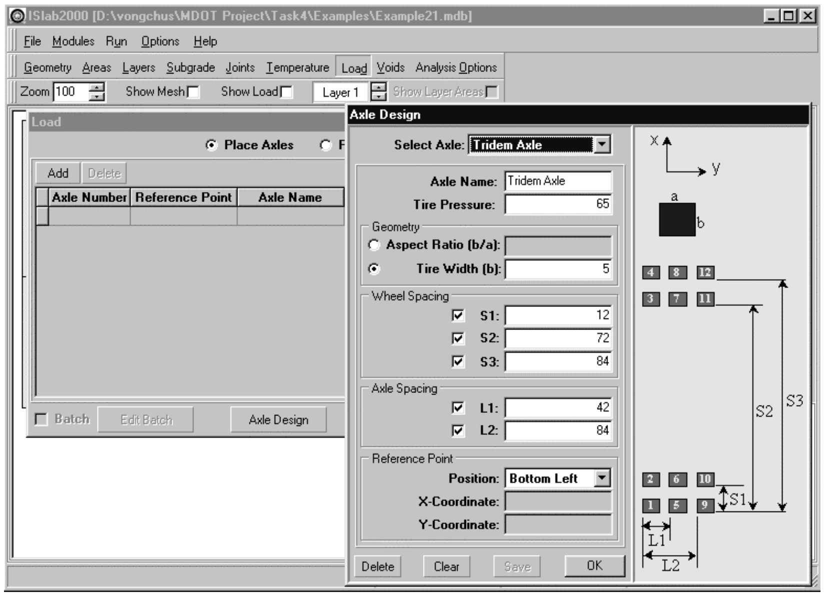


Figure E21-2: Edit Inputs for the Load Module

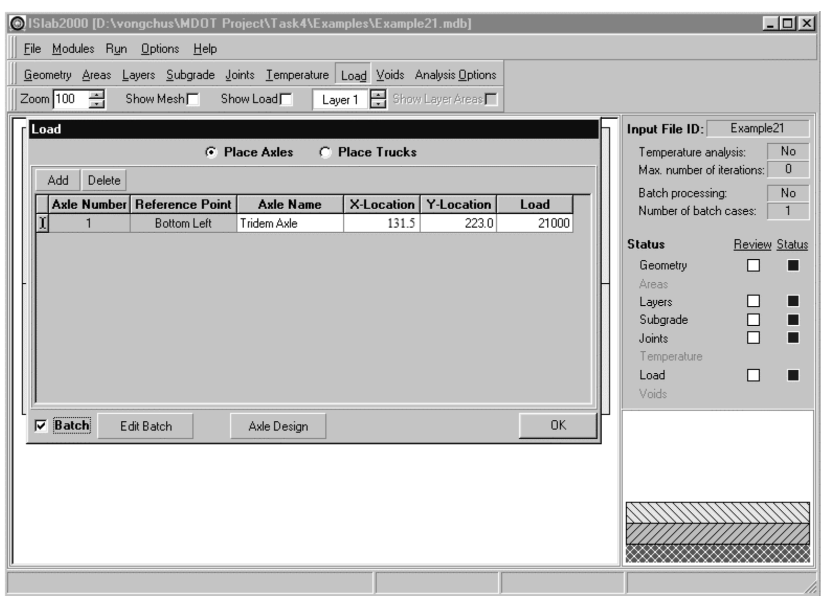


Figure E21-3: Edit Inputs for the Load Module (continued)

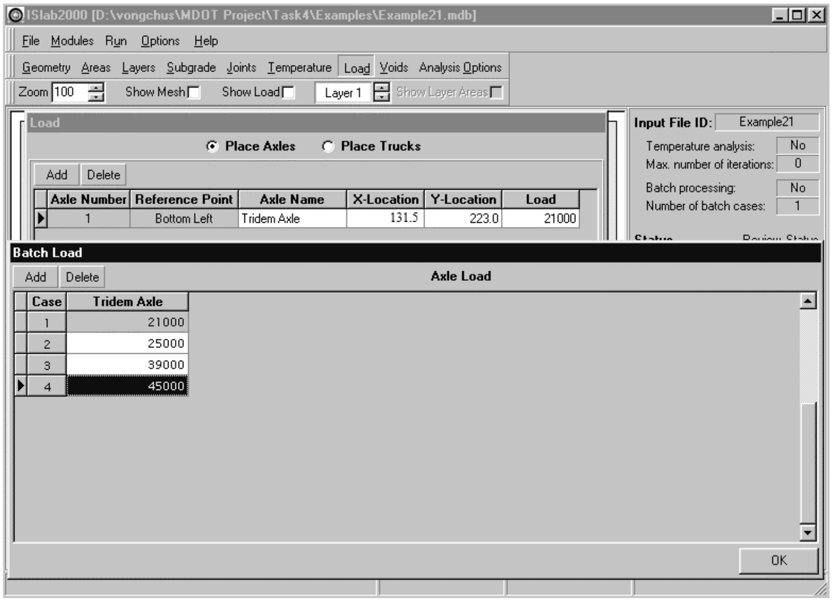


Figure E21-4: Edit Inputs for the Load Module (continued)

Temperature Module

This module is not required for this problem.

Analysis Options Module

Use this module from Example 4.

The main panel should display the pavement structure, loading condition, and meshing as shown in Figure E21-5.

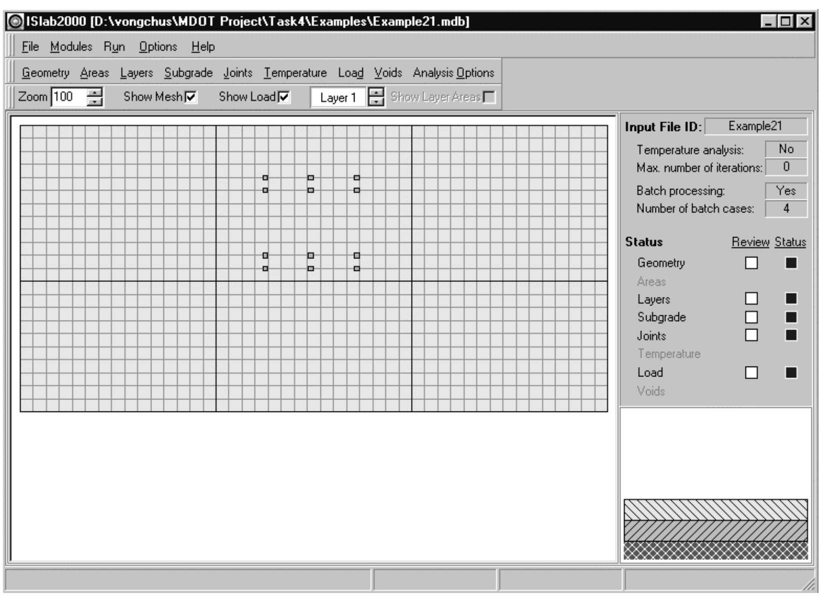


Figure E21-5: Main Panel After the Completion of Inputs

Analysis Results

Axle wt., kips	Stress at the bottom of the PCC, psi	
	Transverse	Longitudinal
21	44.1	57.4
25	51.9	66.5
39	77.6	99.9
45	90.8	113.1

Table E21-1: Analysis Results

> **NOTE**
> Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Stress and deflection contours from ISLAB2000 are also available in Figures E21-6 through E21-8. Figure E21-9 illustrates relationship between maximum stresses and axle weight. Figures E21-10 and E21-11 illustrate the comparison of the stresses between single, tandem, and tridem axle at the same level of loading.

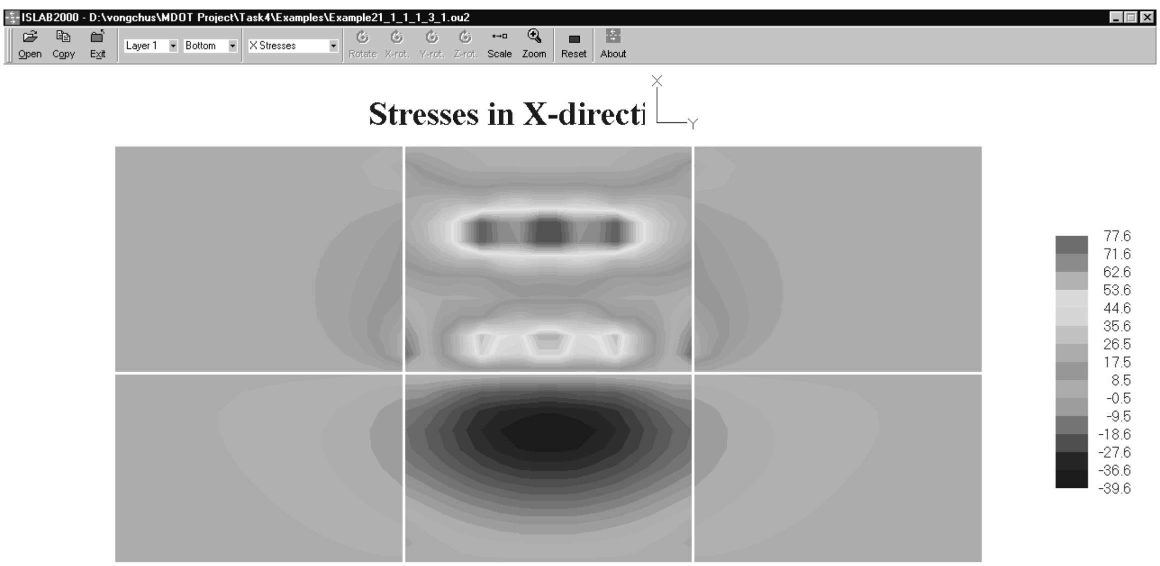


Figure E21-6: Transverse Stress at the Bottom of the PCC Slab, 32-kips Axle Weight

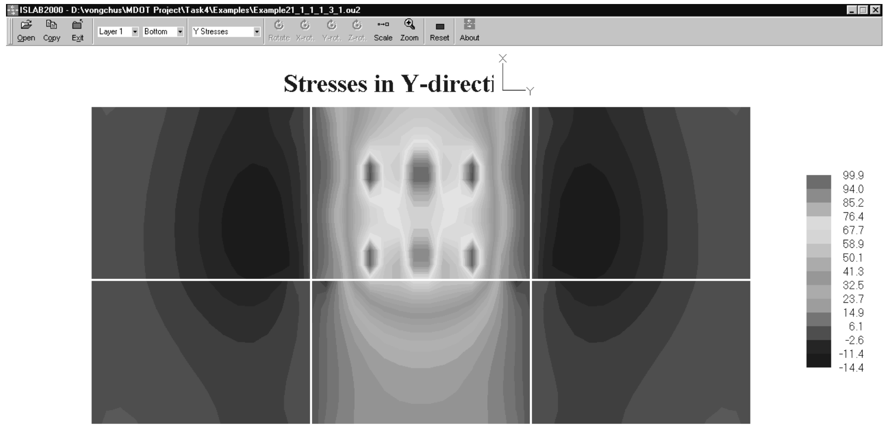


Figure E21-7: Longitudinal Stress at the Bottom of the PCC From ISLAB2000, 32-kips Axle Weight

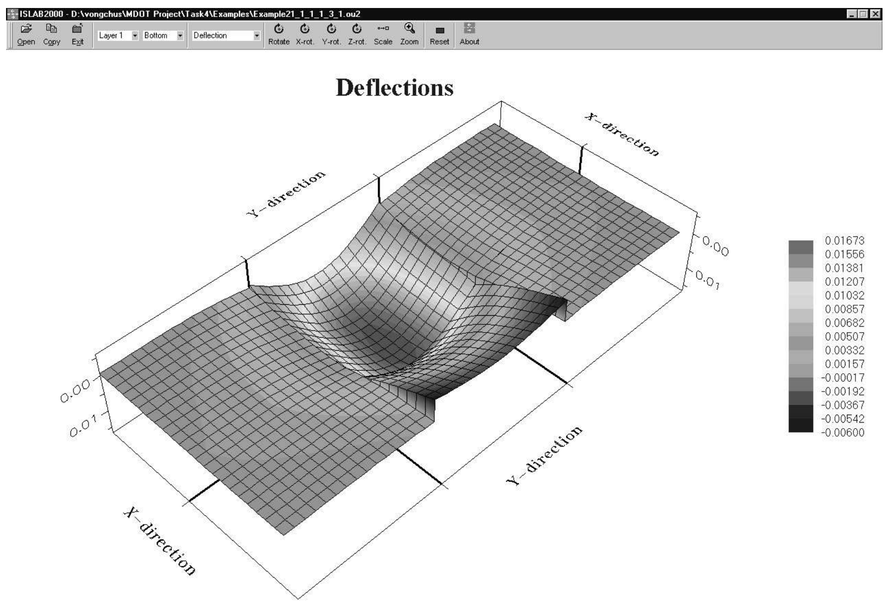


Figure E21-8: Deflection of the PCC slab, 32-kips Axle Weight

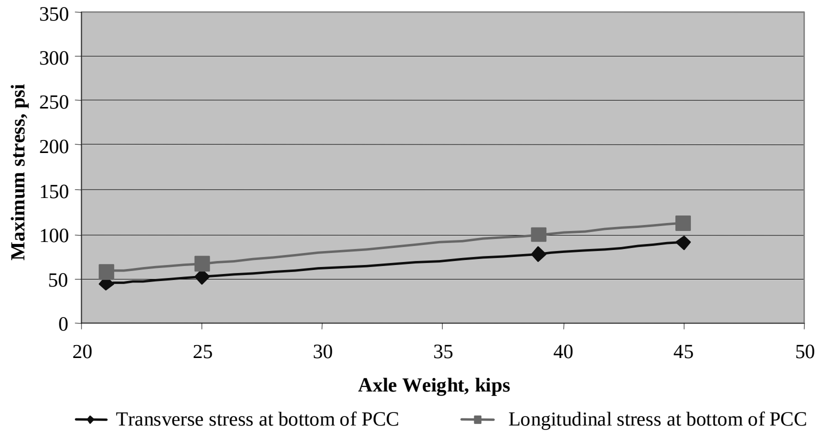


Figure E21-9: Relationship Between Stresses and Axle Weight

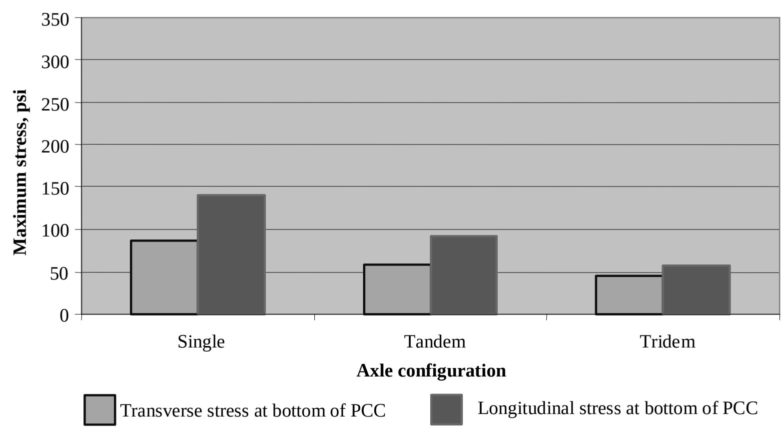


Figure E21-10: Relationship Between Stresses and Axle Type, Axle Weight of 21 kips

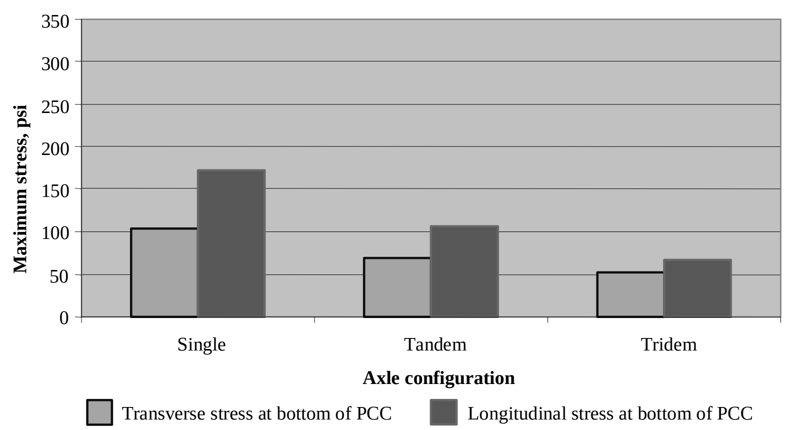


Figure E21-11: Relationship Between Stresses and Axle Type, Axle Weight of 25 kips

Example 22:
Single Axle Edge Loading with Various CTE Values

Problem Statement

Repeat Example 8 but consider several PCC coefficient of thermal expansion, α_{pcc}, of 3, 5, 7, 9x10^{-6} in./in./^{o}F and at the same time, apply temperature differential, ΔT, of +20 ^{o}F. Then compare the results with the results from Example 9 by plotting a graph using the product α.ΔT for X-axis.

Given

PCC coefficient of thermal expansion, α_{pcc}	=	3, 5, 7, 9 x 10^{-6}	in./in./^{o}F
Temperature differential, ΔT	=	+20	^{o}F.

Problem Illustration

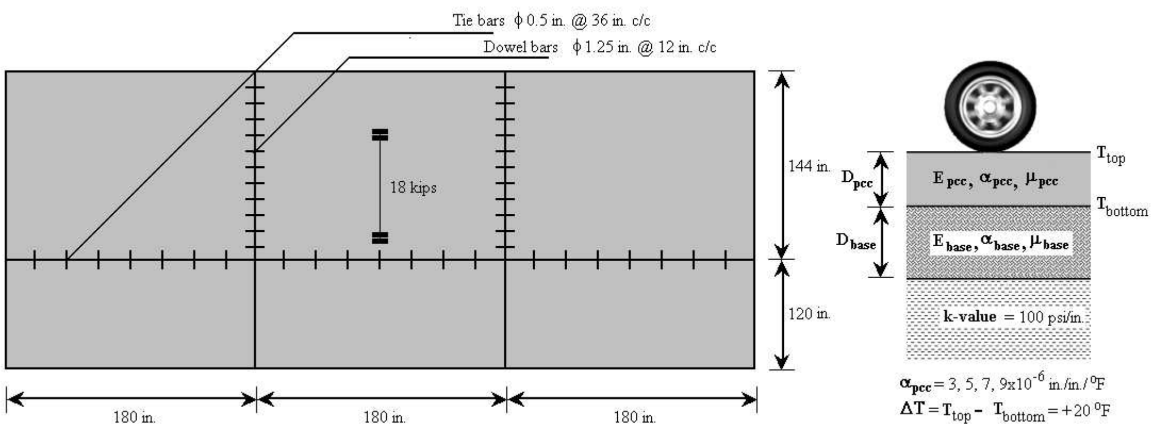


Figure E22-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 8.

Layers Module

Step 1: Follow steps 1 through 5 of this module in Example 14.

Step 2: Click **Insert** three times to add three additional cases, and then enter the PCC coefficient of thermal expansion as identified in the problem statement (see Figure E22-2).

Step 3: Click **OK** to close the layer 1 properties panel, and then click **OK** to close the layers panel.

Subgrade Module

Use this module from Example 8.

Joints Module

Use this module from Example 8.

Load Module

Use this module from Example 8.

Temperature Module

Use this module from Example 16.

Analysis Options Module

Use this module from Example 4.

The main panel should display the pavement structure, loading condition, and meshing as shown in Example 8, Figure E8-12.

Analysis Results

α, x10^{-6} in./in./^{o}F	Stress at the bottom of the PCC, psi	
	Transverse	Longitudinal
3	112.6	180.5
5	139.7	224.5
7	166.7	268.6
9	193.5	313.3

Table E22-1: Analysis Results

α, x10^{-6} in./in./^oF	ΔT, ^oF	$\alpha.\Delta T$, x10^{-6}	Stress at the bottom of the PCC, psi	
			Transverse	Longitudinal
From Example 9				
5	0	0	72.1	114.5
5	10	50	105.9	169.5
5	20	100	139.7	224.5
From Example 22				
3	20	60	112.6	180.5
5	20	100	139.7	224.5
7	20	140	166.7	268.6
9	20	180	193.5	313.3

Table E22-2: Comparison of Analysis Results

NOTE
Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Figure E22-3 illustrates relationship between maximum stresses and PCC coefficient of thermal expansion. Figure E22-4 illustrates relationship between maximum stresses and the product $\alpha.\Delta T$ from this example and Example 9.

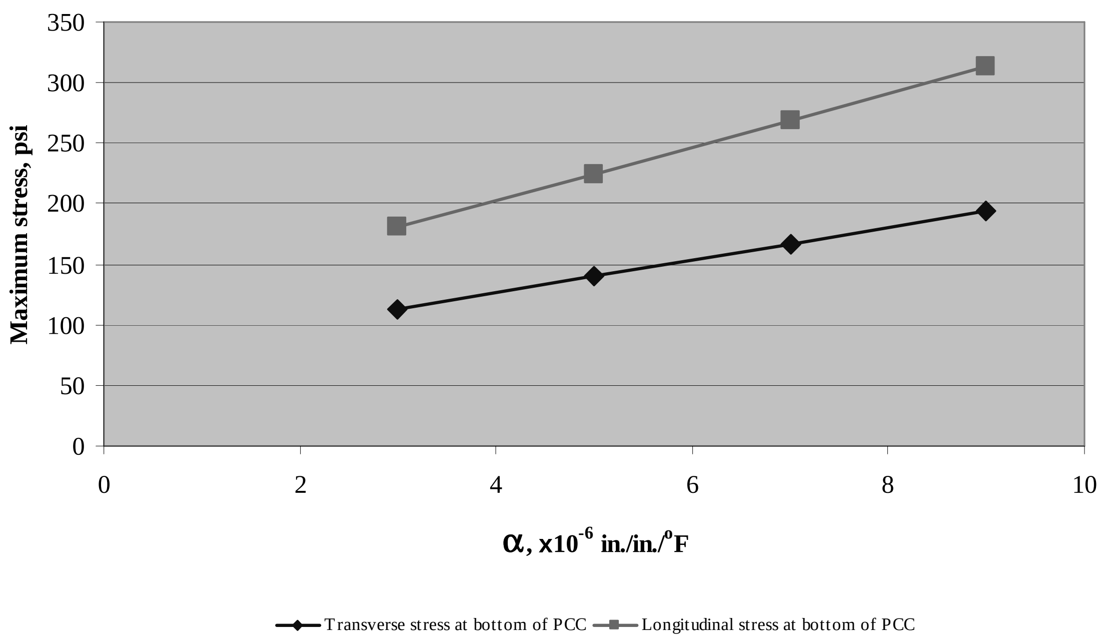


Figure E22-3: Relationship Between Stresses and PCC Coefficient of Thermal Expansion

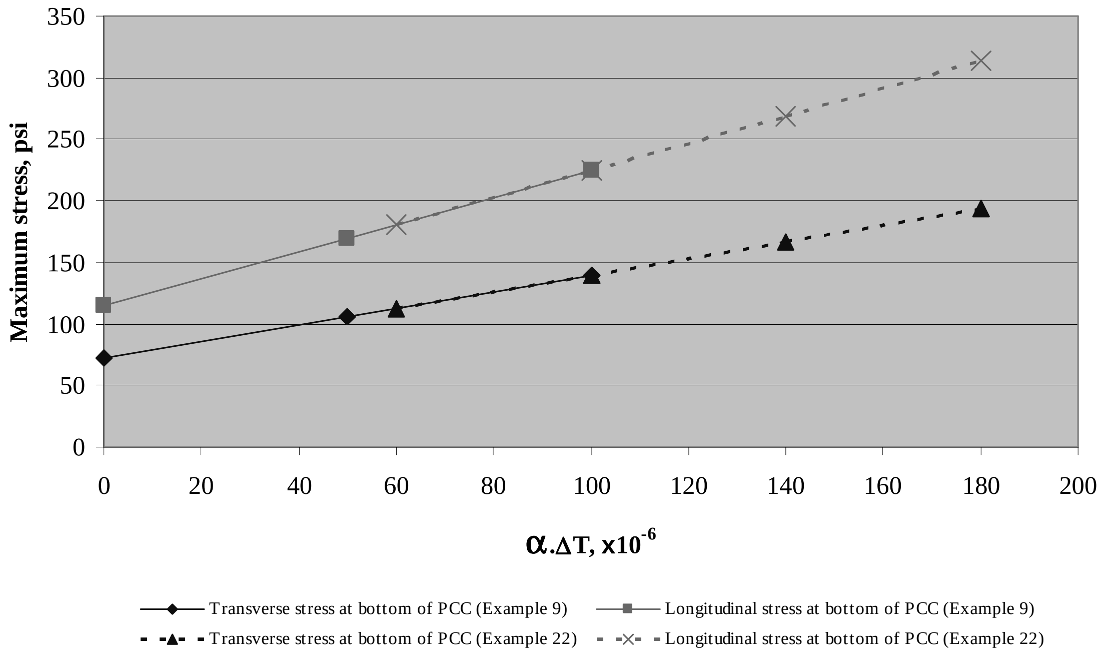


Figure E22-4: Comparison of the Results from Example 9 and Example 22

Example 23: Single Axle Wander

Problem Statement

Analyze three pavement systems: 1) 12-ft lane width with tied PCC shoulder (Example 8), 2) 12-ft lane width with untied AC shoulder, 3) 12-ft lane width with untied AC shoulder. Also consider lateral wanders of axle loading from shoulder toward the lane center: -12, -6, 0, 6, 12, 18, 30, 60 in. (distance from shoulder to outer edge of wheel load)

Given

Lateral support condition	=	PCC shoulder, AC shoulder, widened lane	
Lateral wanders	=	-12, -6, 0, 6, 12, 18, 30, 60	in.

Problem Illustration

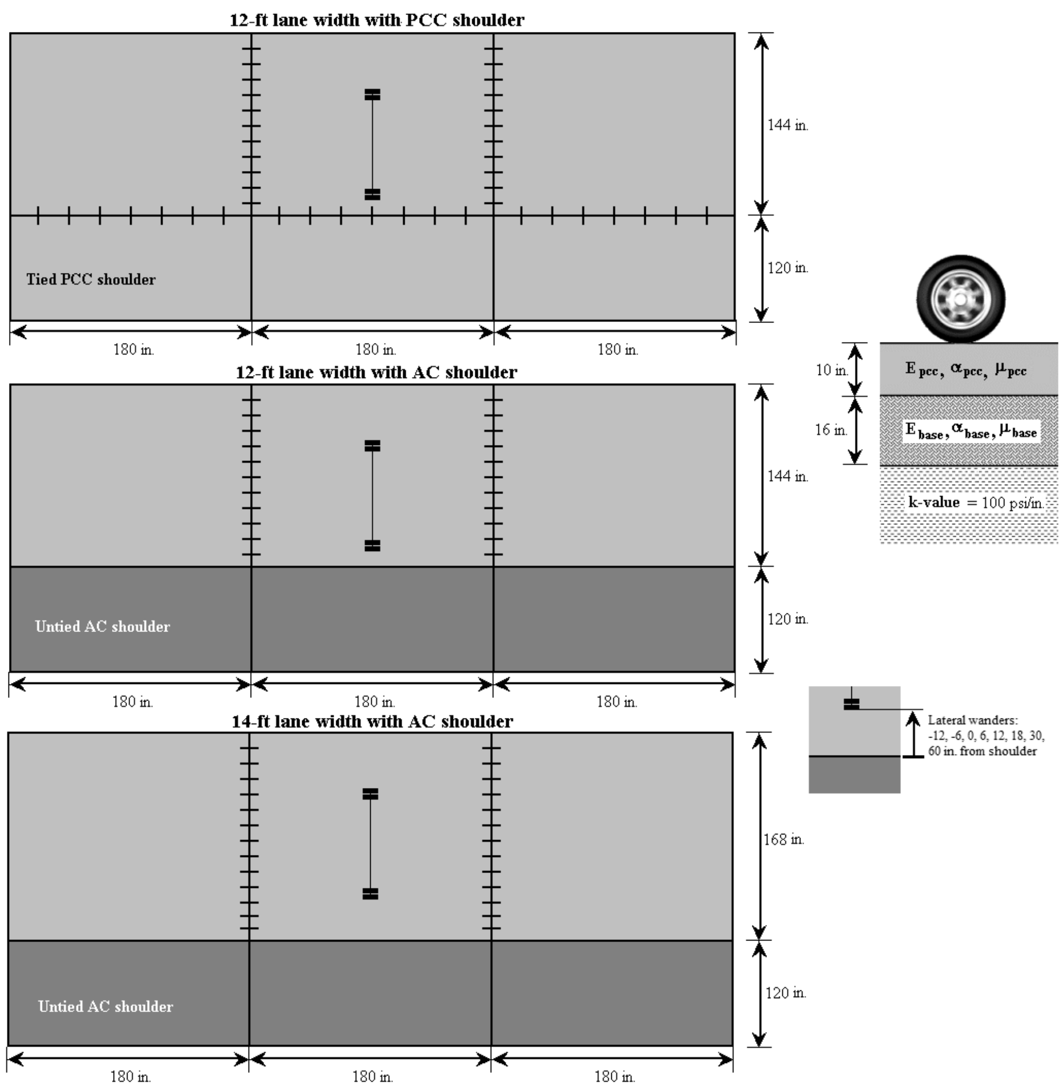


Figure E23-1: Problem Illustration

Solution

Part 1: 12-ft lane width with tied PCC shoulder

Geometry Module

Use this module from Example 8.

Layers Module

Use this module from Example 8.

Subgrade Module

Use this module from Example 8.

Joints Module

Use this module from Example 8.

Load Module

(see Figure E23-2)

Step 1: Follow steps 1 through 9 of this module in Example 8.

Step 2: Enter X-location and Y-location information to locate the wheel load. X-location and Y-location for an edge loading condition can be computed as shown below:

$$X-location = Shoulder\ width + +Lateral\ \ placement$$

$$= 120 + +Lateral\ \ placement$$

X-location inputs for all eleven lateral placements considered in this problem are summarized in Table E23-1.

$$Y-location = Joint\ spacing + \frac{Joint\ spacing}{2} - \frac{wheel\ load\ length}{2}.$$

$$= 180 + \frac{180}{2} - \frac{10}{2} = 265\,in$$

Step 3: Type the load for the single axle (18,000 lbs for this example).

Step 4: Click **OK** to close the load panel.

Temperature Module

This module is not required for this problem.

Analysis Options Module

This module is not required for this problem.

At this stage, all the steps for inputs are completed for the first of 11 lateral placements. If all the inputs are correct, the main panel should display the pavement structure, loading condition, and meshing as shown in Figure E23-3. For the next lateral placement, apply the X-location as the calculated value to be used shown in Table E23-1.

Lateral placement (in.)	X-Location input
-12	108
-6	114
0	120
6	126
12	132
18	138
30	150
48	168

Table E23-1: X-location Input for each Lateral Placement

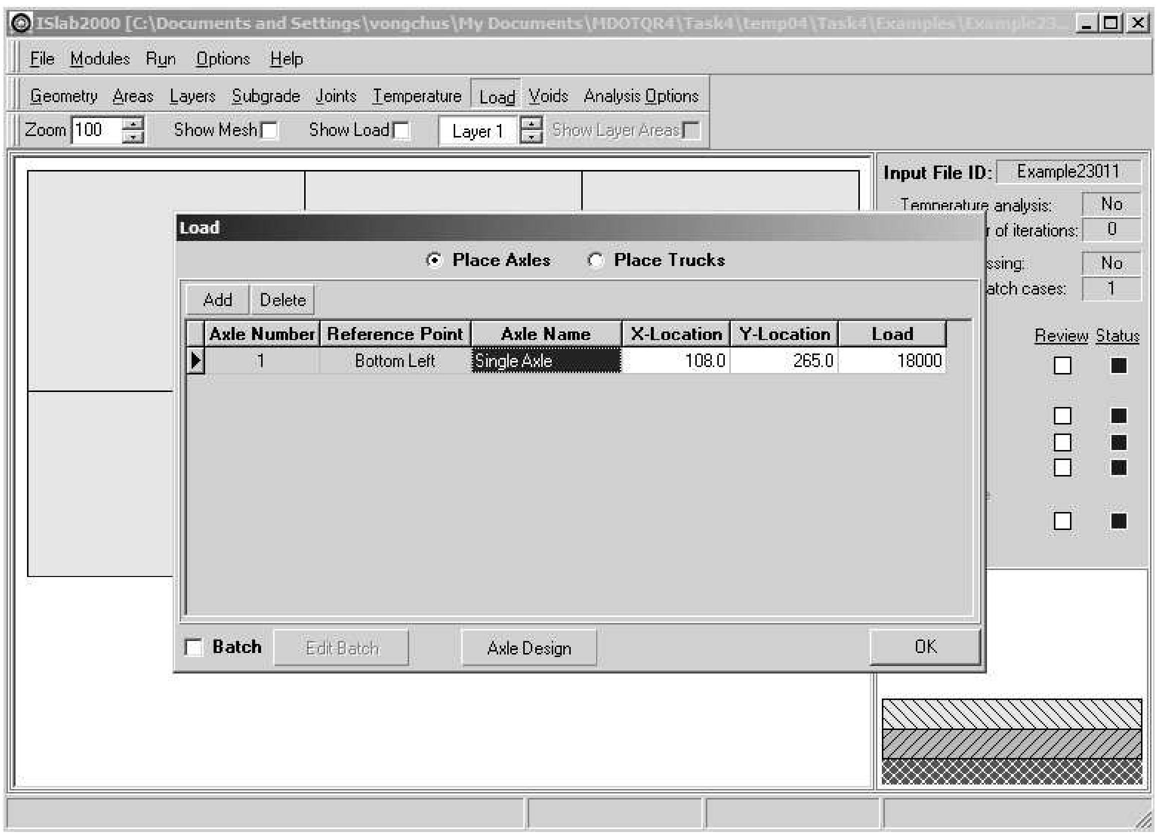


Figure E23-2: Edit Inputs for the Load Module (12-ft lane width)

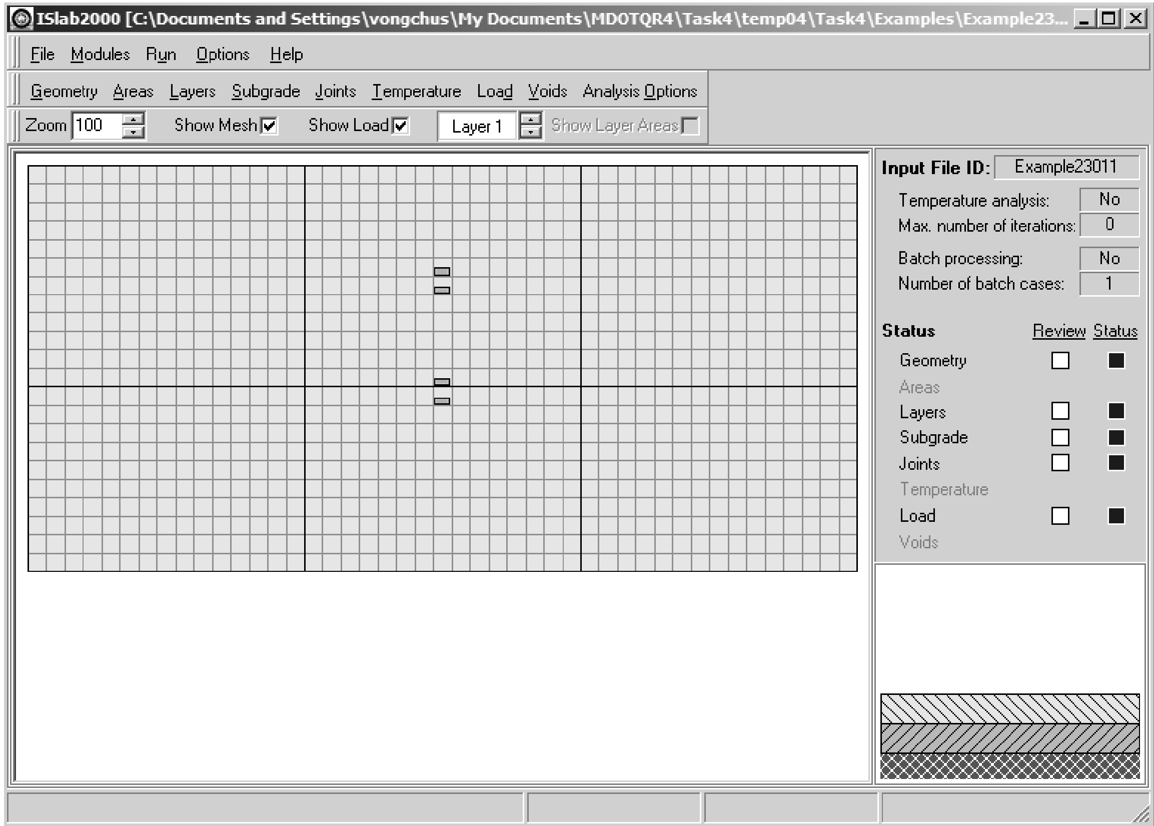


Figure E23-3: Main Panel After the Completion of Inputs (12-ft lane width with PCC shoulder)

Part 2: 12-ft lane width with untied AC shoulder

Geometry Module

Use this module from Example 8.

Area Module

(see Figure E23-4)

Step 1: Click **Area** to open the area panel, click **Add** to add an area, and then enter **Shoulder** in the **Area Name** field.

Step 2: Select **Coordinates** in the **Coordinate Type** box.

Step 3: Enter the coordinate for the shoulder area as identified in the problem illustration.

Step 4: Click **OK** to close the area definition panel.

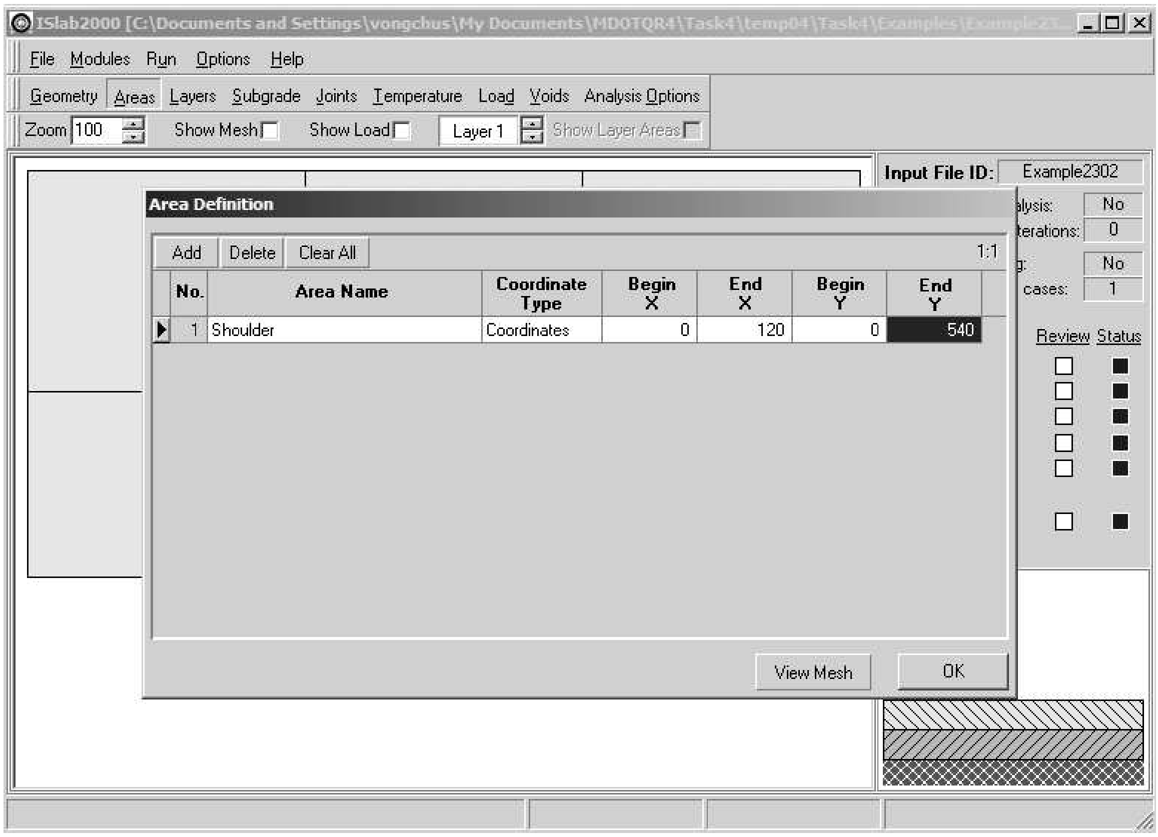


Figure E23-4: Edit Inputs for the Area Module

Layers Module

(see Figures E23-5 and E23-6)

Step 1: Follow steps 1 through 4 of this module in Example 8.

Step 2: On Layer 1, select **Exception**, and then click **Edit Exception** to open the exception properties for layer 1 panel.

Step 3: Click **Insert** to add an additional area, and then select **Shoulder** in the **Area Name** box.

Step 4: Enter the material properties for AC shoulder as shown in Figure E23-6.

Step 5: Click **OK** to close the layers panel.

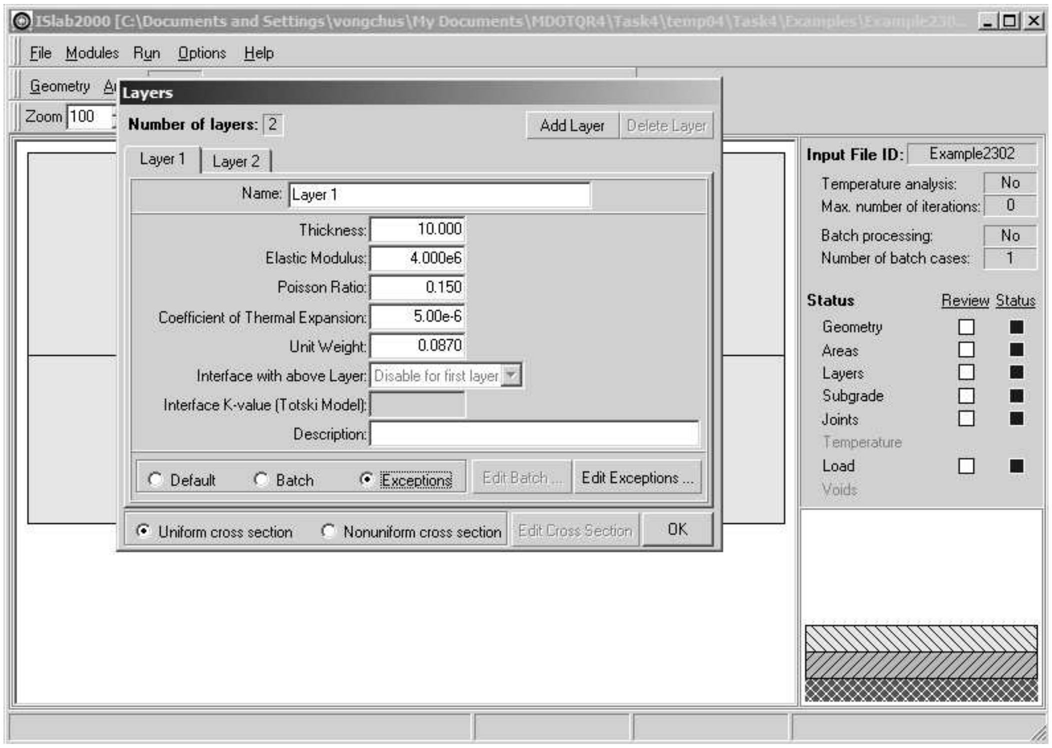


Figure E23-5: Edit Inputs for the Layers Module

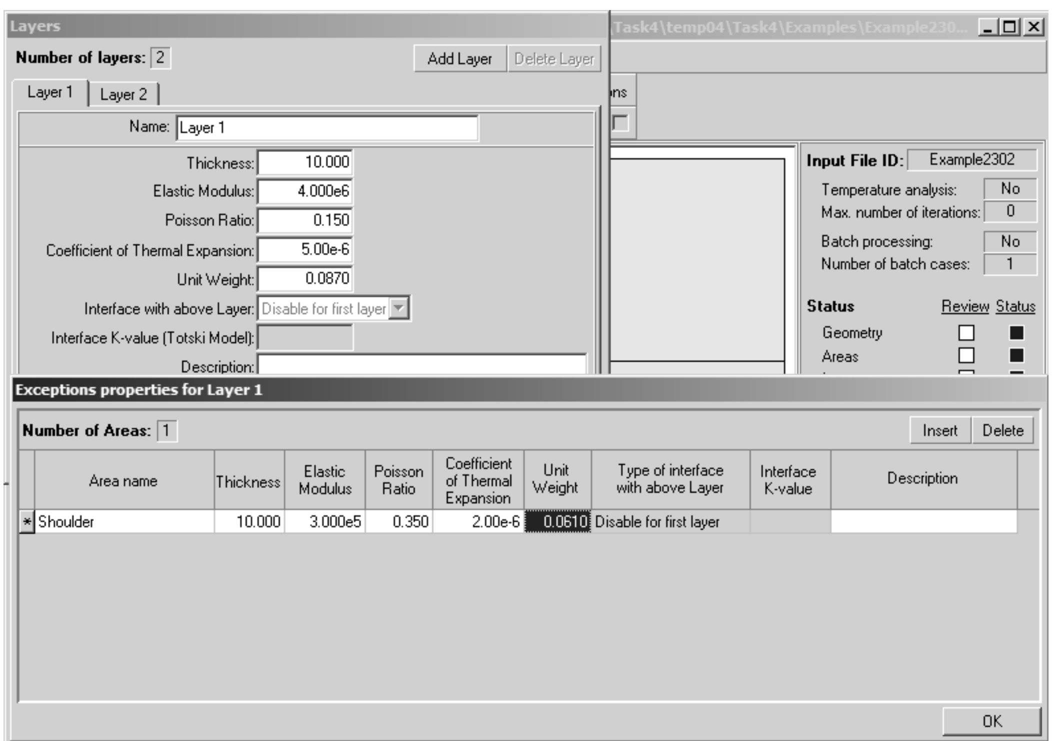


Figure E23-6: Edit Inputs for the Layers Module (continued)

Subgrade Module

Use this module from Example 8.

Joints Module

(see Figure E23-7)

Step 1: Click **Joints** to open the joints panel.

Step 2: In the **Joints in x-direction** section, select **Specify joint parameters**, select **AGG Interlock** in the **Joint type** field, and then enter the aggregate factor in the **AGG factor** field (assumed 1,000 psi.)

Step 3: Follow steps 3 through 5 of this module in Example 8.

Load Module

Use this module from 12-ft lane width with PCC shoulder in this problem.

Temperature Module

This module is not required for this problem.

Analysis Options Module

This module is not required for this problem.

At this stage, all the steps for inputs are completed for the first of 11 lateral placements. If all the inputs are correct, the main panel should display the pavement structure, loading condition, and meshing as shown in Figure E23-8. For the next lateral placement, apply the X-location as the calculated value to be used shown in Table E23-1.

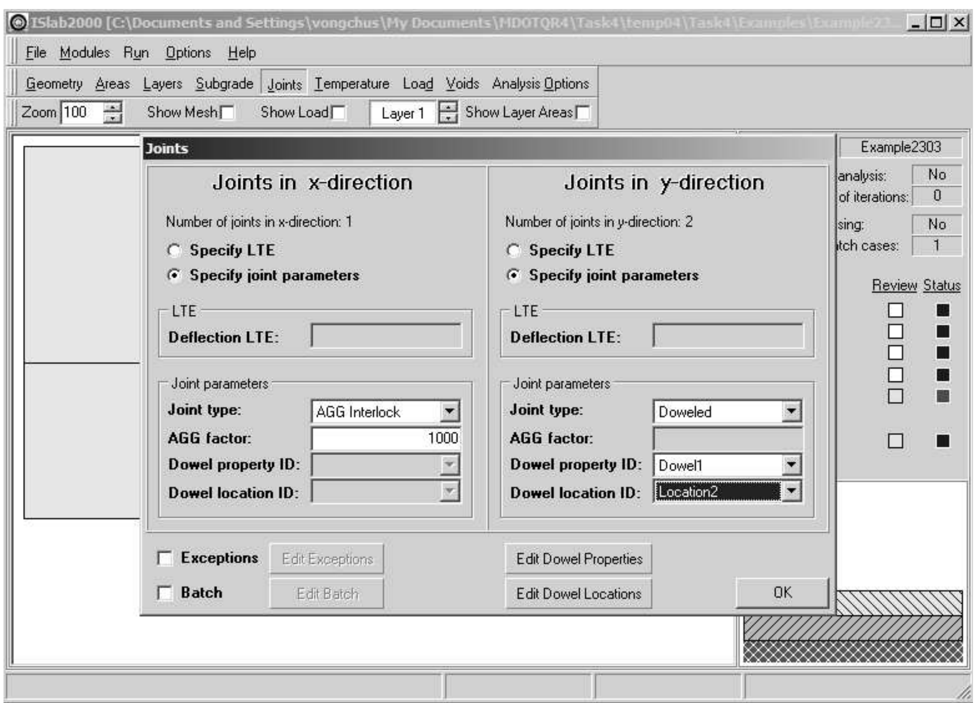


Figure E23-7: Edit Inputs for the Joints Module (14-ft lane width with AC shoulder)

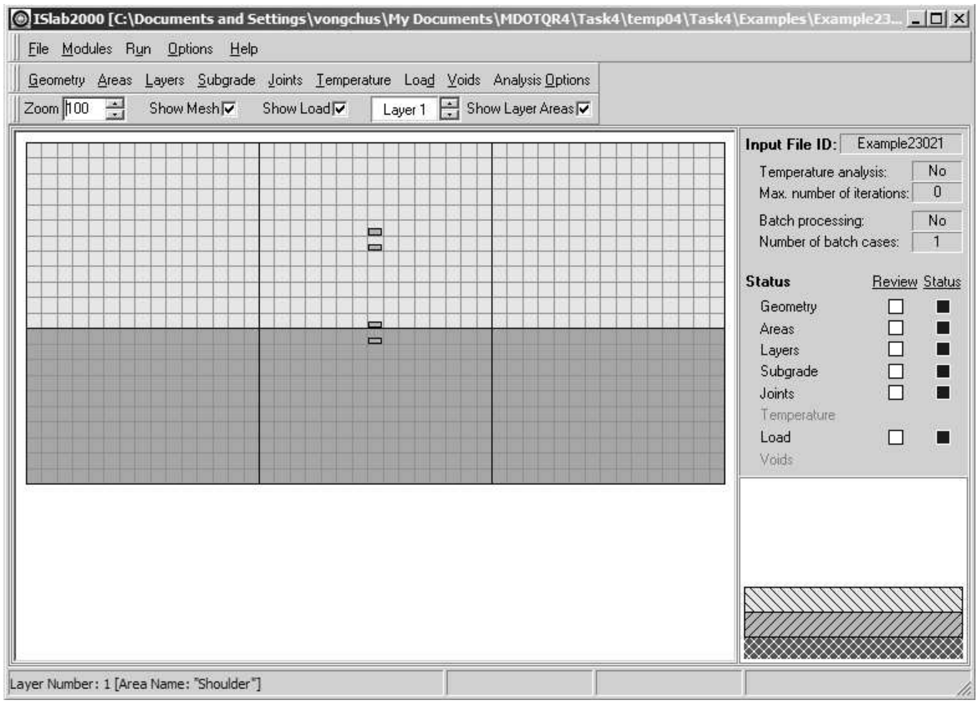


Figure E23-8: Main Panel After the Completion of Inputs (12-ft lane width with AC shoulder)

Part 3: 14-ft lane width with untied AC shoulder

Geometry module

(see Figure E23-9)

Step 1: Click **Geometry** to open the geometry panel.

Step 2: On the geometry panel, click **Insert** two times on the **X-direction** side to add additional slabs, and then enter the shoulder width (120 inches) and the lane width (168 inches).

Step 3: Follow steps 3 through 5 of this module in Example 8.

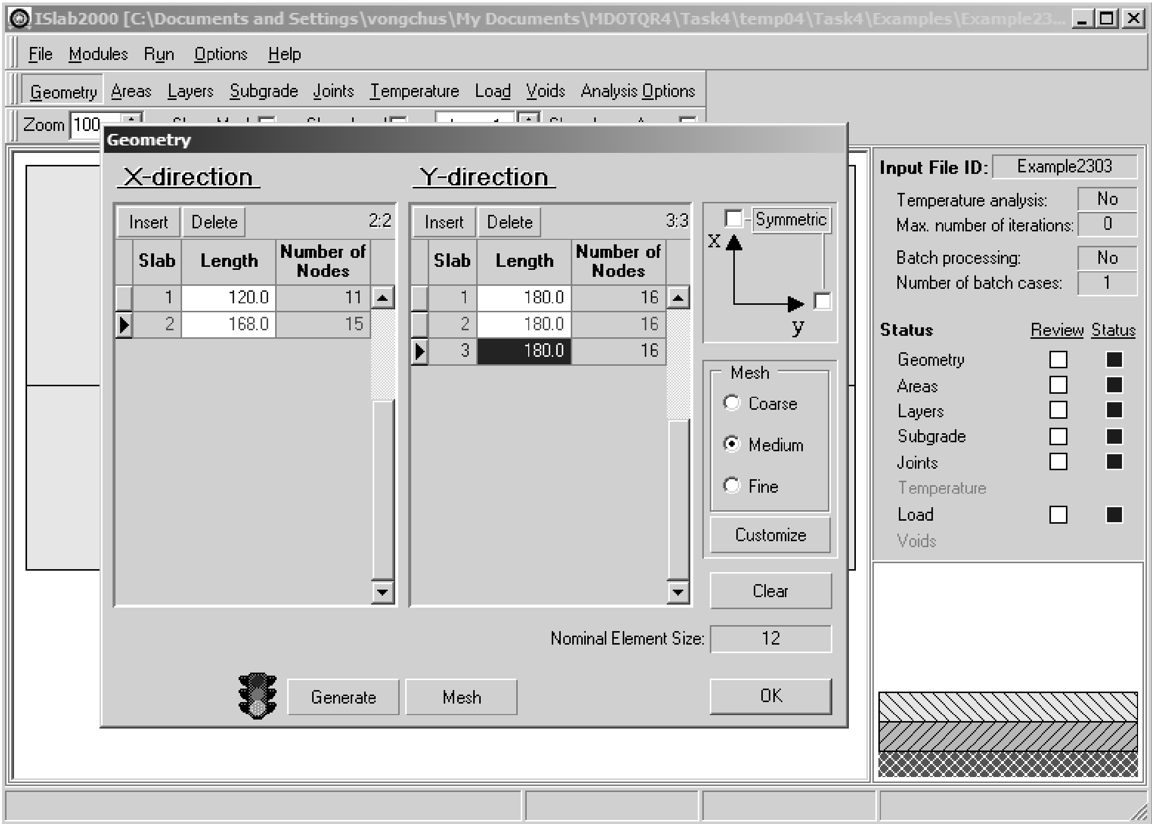


Figure E23-9: Edit Inputs for the Geometry Module

Area Module

Use this module from 12-ft lane width with ACC shoulder in this problem.

Layers Module

Use this module from 12-ft lane width with ACC shoulder in this problem.

Subgrade Module

Use this module from Example 8.

Joints Module

Use this module from 12-ft lane width with ACC shoulder in this problem.

Load Module

(see Figure E23-10)

Step 1: Follow steps 1 through 9 of this module in Example 8.

Step 2: Enter X-location and Y-location information to locate the wheel load. X-location and Y-location for an edge loading condition can be computed as shown below:

$$X-location = Shoulder\ \ width + Lateral\ \ placement$$

$$= 120 + Lateral\ \ placement$$

X-location inputs for all eleven lateral placements considered in this problem are also summarized in Table E23-1.

$$Y-location = Joint\ spacing + \frac{Joint\ spacing}{2} - \frac{wheel\ load\ length}{2}.$$

$$= 180 + \frac{180}{2} - \frac{10}{2} = 265\ in$$

Step 3: Enter the load for the single axle (18,000 lbs for this example).

Step 4: Click **OK** to close the load panel.

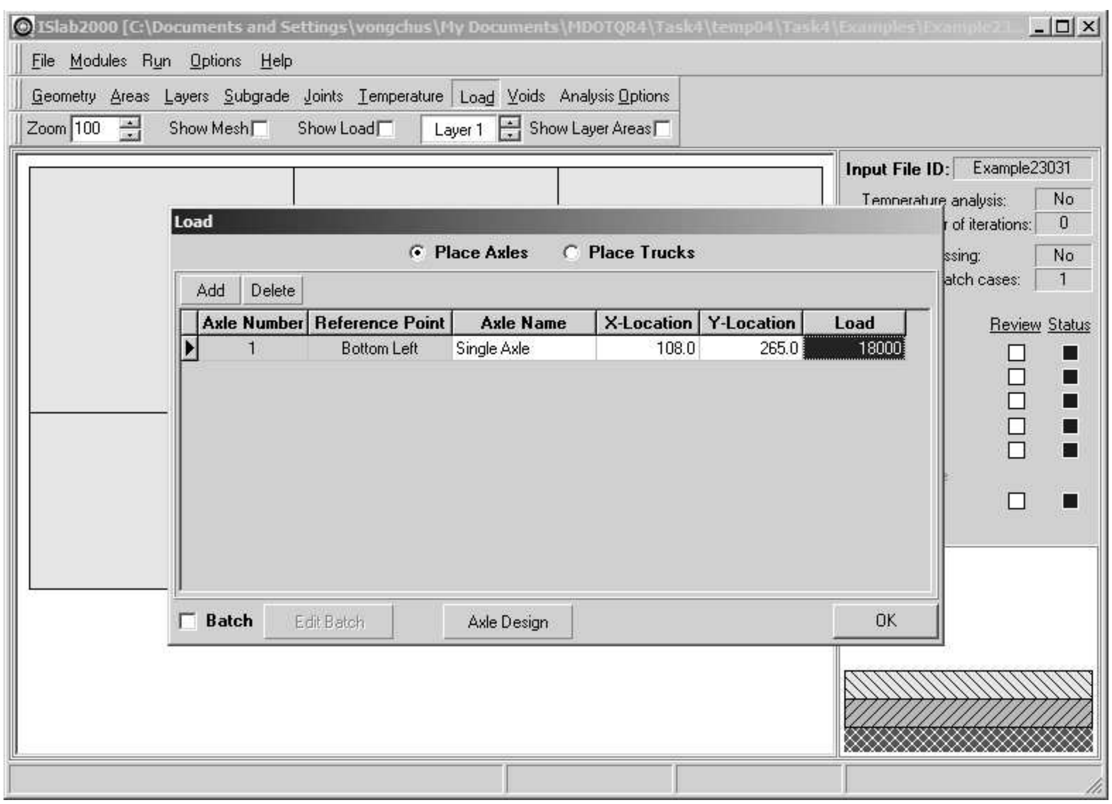


Figure E23-10: Edit Inputs for the Load Module

Temperature Module

This module is not required for this problem.

Analysis Options Module

This module is not required for this problem.

At this stage, all the steps for inputs are completed for the first of 11 lateral placements. If all the inputs are correct, the main panel should display the pavement structure, loading condition, and meshing as shown in Figure E23-11. For the next lateral placement, apply the X-location as the calculated value to be used shown in Table E23-1.

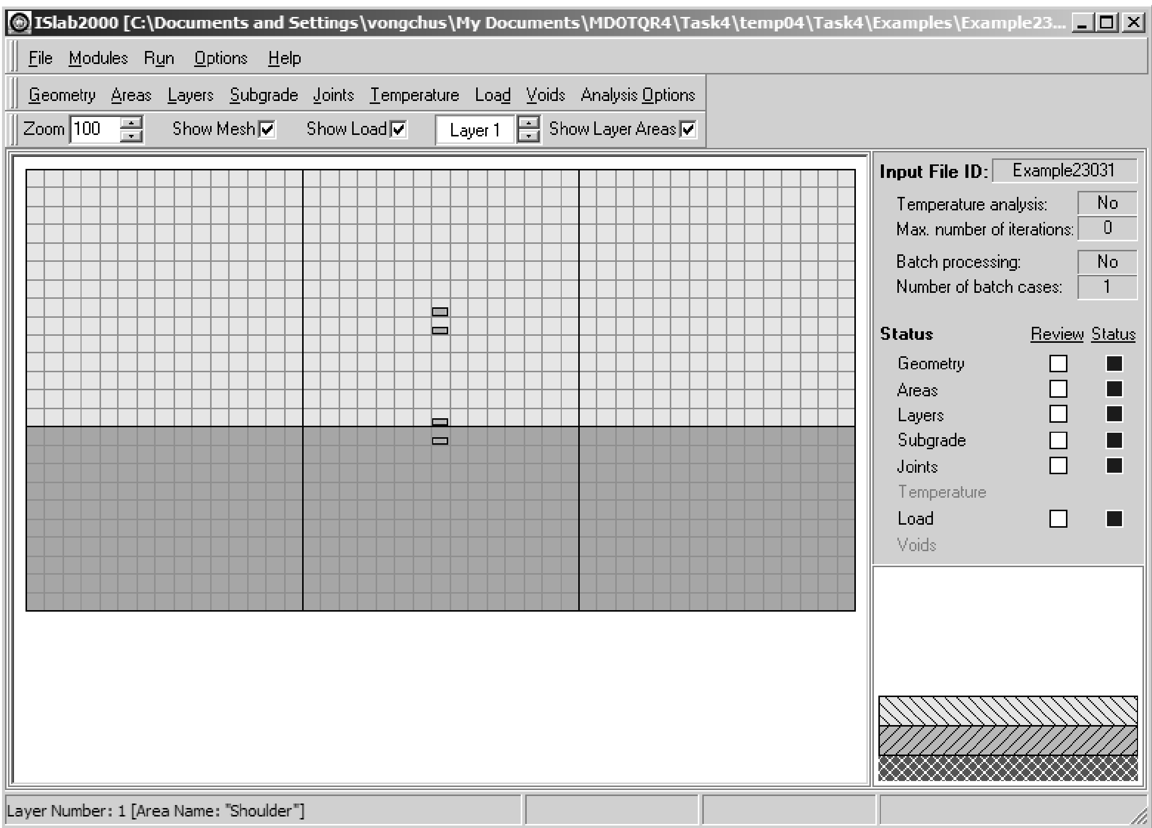


Figure E23-11: Main Panel After the Completion of Inputs (14-ft lane width with AC shoulder)

Analysis Results

Table E23-2 summarizes maximum for all lateral placements and lateral support conditions. The relationship between maximum stress and lateral placement for each lateral support condition is illustrated in Figures E23-12 and E23-13 for transverse and longitudinal stress at the bottom of the PCC slab respectively.

NOTE
Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Lateral placement (in.)	Lateral support condition		
	12-ft lane width with PCC shoulder	12-ft lane width with AC shoulder	14-ft lane width with AC shoulder
Transverse stress at bottom of PCC			
-12	70.6	65.9	65.2
-6	71.4	68.3	68.6
0	73.9	61.8	62.0
6	75.3	64.8	66.9
12	74.6	67.9	72.4
18	73.4	67.7	74.9
30	77.5	67.8	76.8
48	65.2	61.4	76.3
Longitudinal stress at bottom of PCC			
-12	122.0	155.4	154.6
-6	119.6	131.1	130.2
0	115.5	206.7	205.6
6	115.0	165.7	164.7
12	115.5	143.5	142.3
18	119.7	135.3	133.8
30	127.2	130.1	123.1
48	165.8	167.2	123.6

Table E23-2: Analysis Results

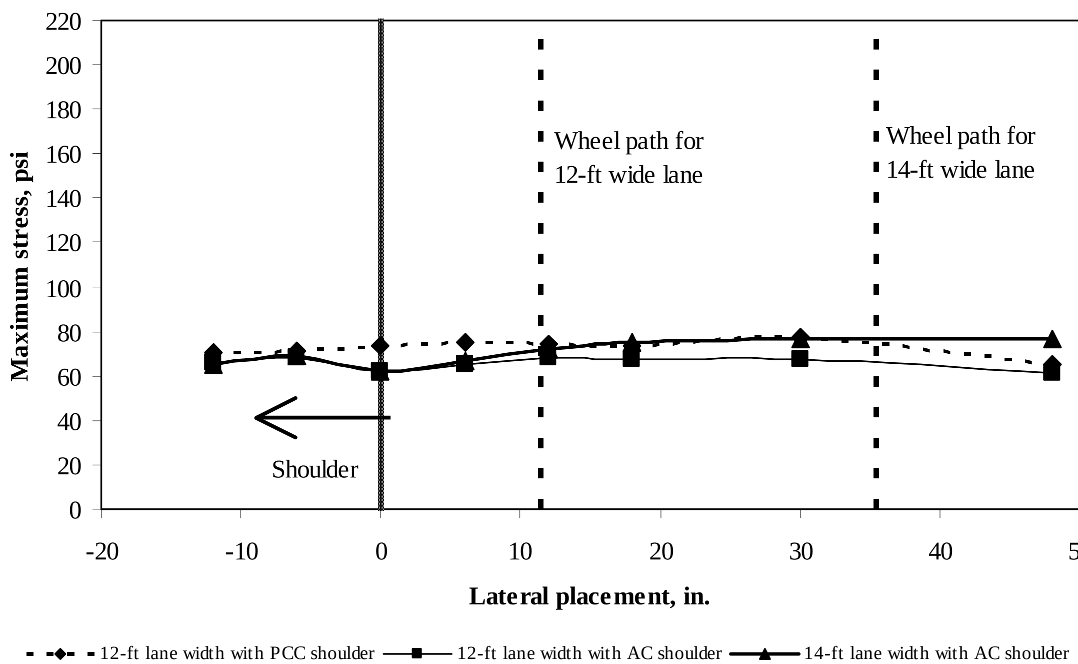


Figure E23-12: Relationship between transverse stress at the bottom of the PCC slab and lateral placement for each lateral support condition

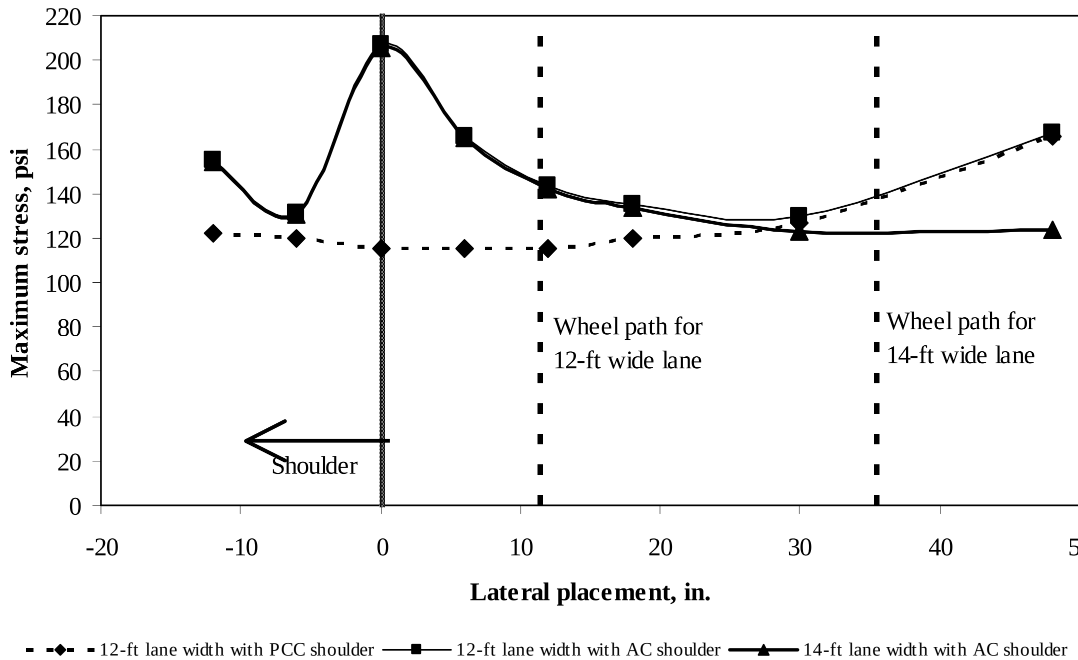


Figure E23-13: Relationship between longitudinal stress at the bottom of the PCC slab and lateral placement for each lateral support condition

Example 24: Single Axle with Various Joint Spacing

Problem Statement

Repeat Example 8 but consider joint spacing of 315 and 492 in. Then, compare the results with the results from Example 8.

Given

Joint spacing	=	315, 492	in.

Problem Illustration

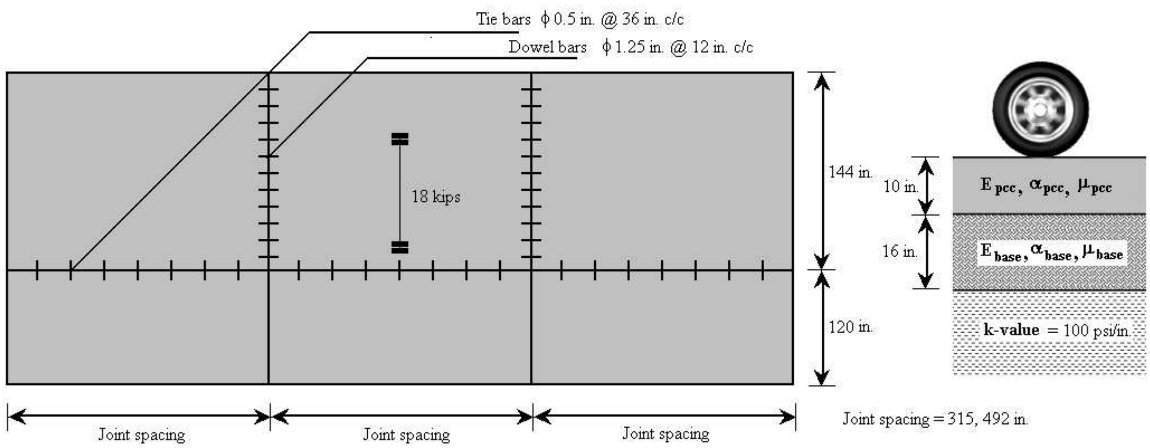


Figure E24-1: Problem Illustration

Solution

Part 1: 315-in. joint spacing

Geometry Module

(see Figure E24-2)

Step 1: Follow steps 1 and 2 of this module in Example 8.

Step 2: Click **Insert** three times on the **Y-direction** side to add additional slabs, and then type the joint spacing (315 inches for this example).

Step 3: Follow steps 4 and 5 of this module in Example 8.

Layers Module

Use this module from Example 8.

Subgrade Module

Use this module from Example 8.

Joints Module

Use this module from Example 8.

Load Module

(see Figure E24-3)

Step 1: Follow steps 1 through 9 of this module in Example 8.

Step2: Enter X-location and Y-location to locate the wheel load. X-location and Y-location for edge loading condition can be computed as shown below:

$$X-location = Shoulder\ width + Distance\ dual\ wheel\ center\ to\ shoulder$$
$$- Distance\ dual\ wheel\ center\ to\ reference\ point$$

$$= 120 + 20 - \left(\frac{5}{2} + \frac{12}{2}\right) = 131.5\ in$$

$$Y-location = Joint\ spacing + \frac{Joint\ spacing}{2} - \frac{wheel\ load\ length}{2}.$$

$$= 315 + \frac{315}{2} - \frac{10}{2} = 467.5\ in$$

Step 3: Follow steps 11 and 12 of this module of Example 8.

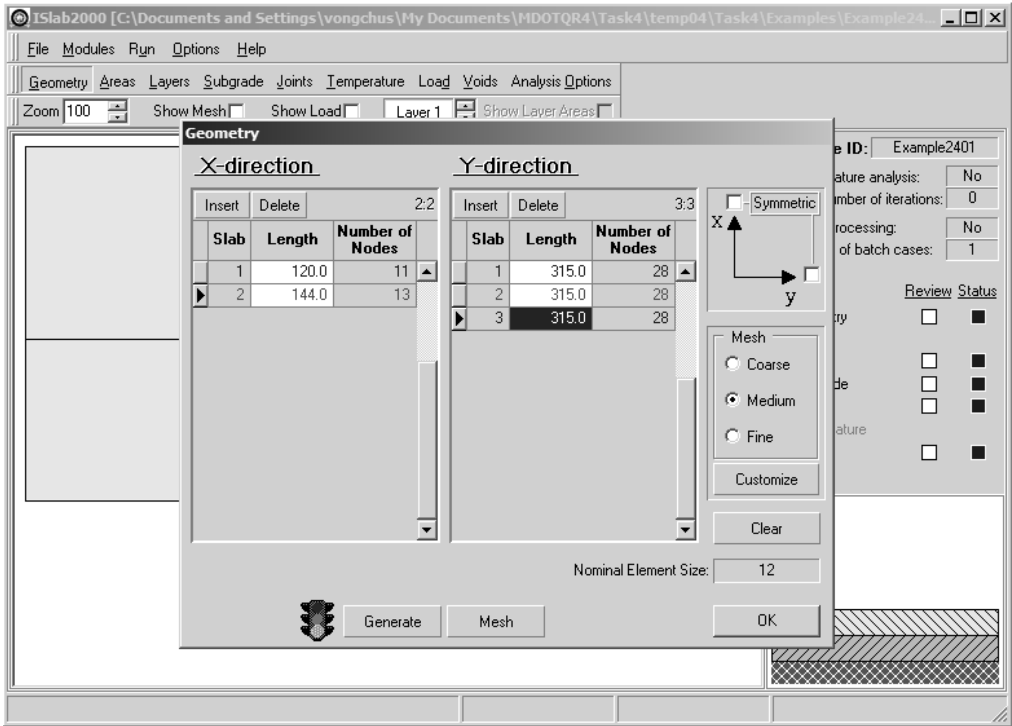


Figure E24-2: Edit Inputs for the Geometry Module

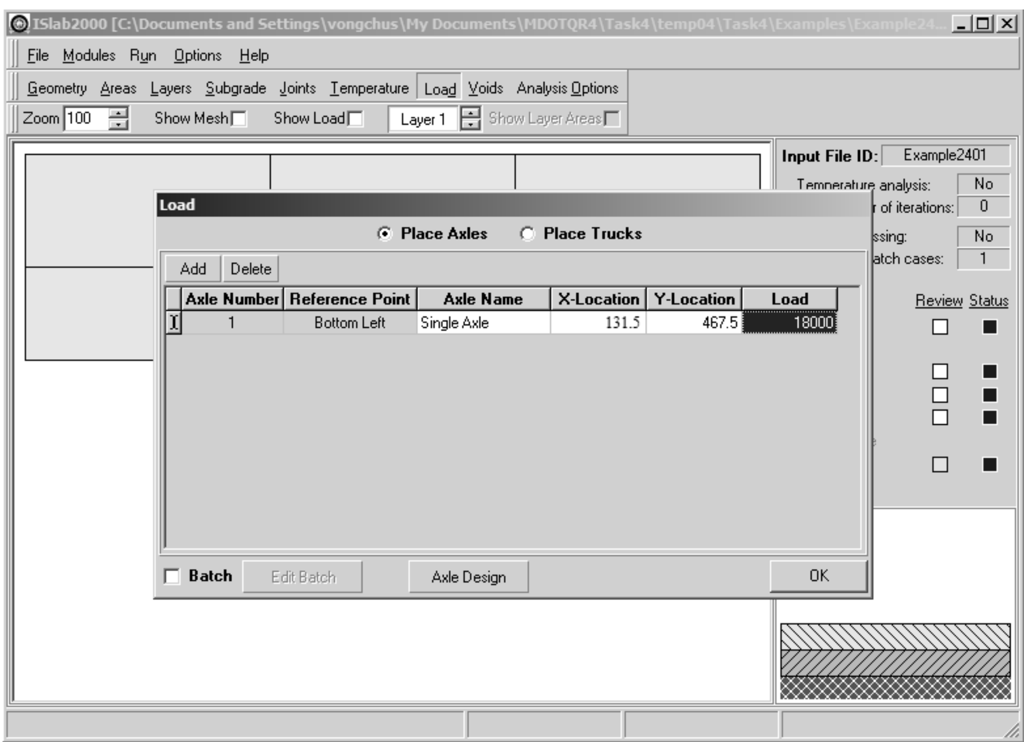


Figure E24-3: Edit Inputs for the Load Module

Temperature Module

This module is not required for this problem.

Analysis Options Module

This module is not required for this problem.

The main panel should display the pavement structure, loading condition, and meshing as shown in Figure E24-4.

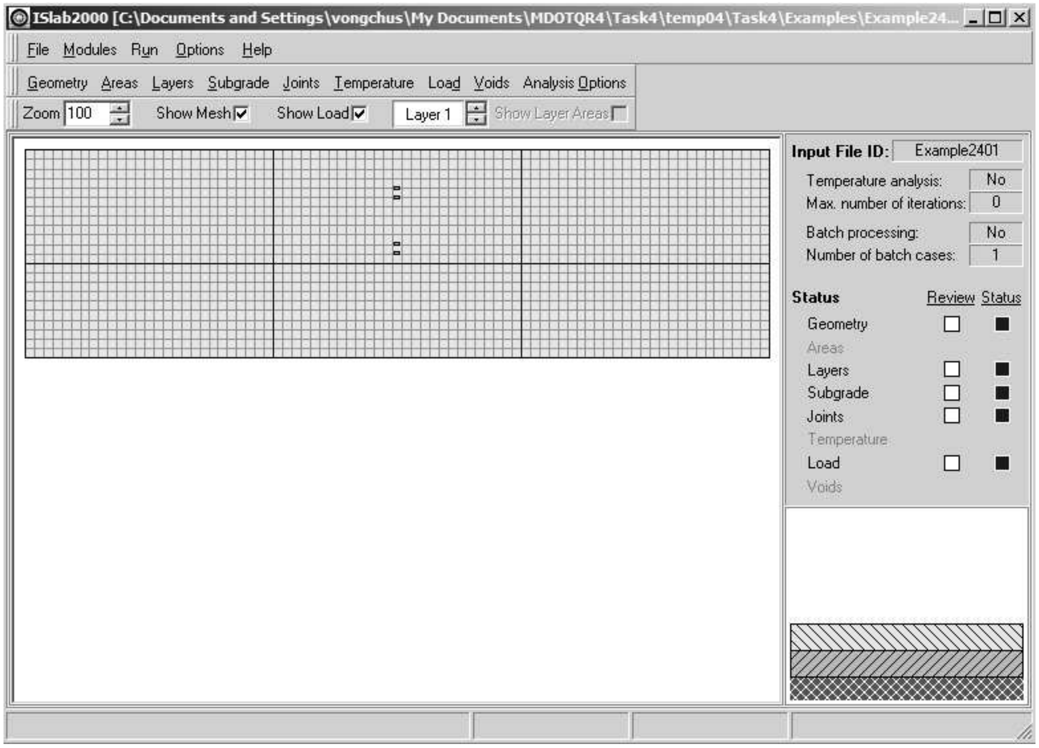


Figure E24-4: Main Panel After the Completion of Inputs (315-in. joint spacing)

Part 2: 492-in. joint spacing

Geometry Module

(see Figure E24-5)

Step 1: Follow steps 1 and 2 of this module in Example 8.

Step 2: Click **Insert** three times on the **Y-direction** side to add three additional slabs, and then enter the joint spacing (492 inches for this example).

Step 3: Follow steps 4 and 5 of this module in Example 8.

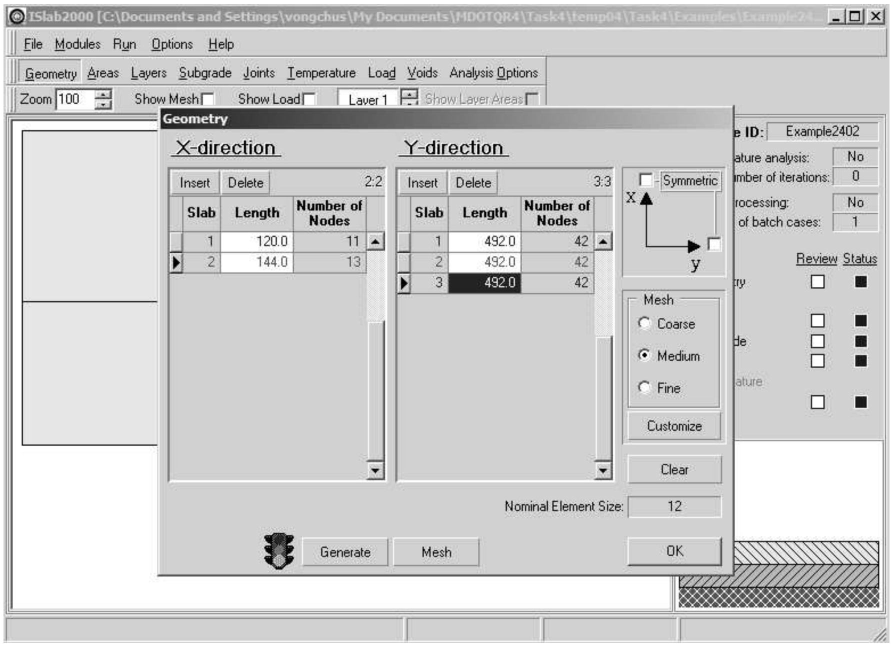


Figure E24-5: Edit Inputs for the Geometry Module

Layers Module

Use this module from Example 8.

Subgrade Module

Use this module from Example 8.

Joints Module

Use this module from Example 8.

Load Module

(see Figure E24-6)

Step 1: Follow steps 1 through 9 of this module in Example 8.

Step2: Type X-location and Y-location to locate the wheel load. X-location and Y-location for edge loading condition can be computed as shown below:

$$X-location = Shoulder\ width + Distance\ dual\ wheel\ center\ to\ shoulder$$
$$-\ Distance\ dual\ wheel\ center\ to\ reference\ point$$

$$= 120 + 20 - \left(\frac{5}{2} + \frac{12}{2}\right) = 131.5\ in$$

$$Y-location = Joint\ spacing + \frac{Joint\ spacing}{2} - \frac{wheel\ load\ length}{2}.$$

$$= 315 + \frac{315}{2} - \frac{10}{2} = 467.5\ in$$

Step 3: Follow steps 11 and 12 of this module in Example 8.

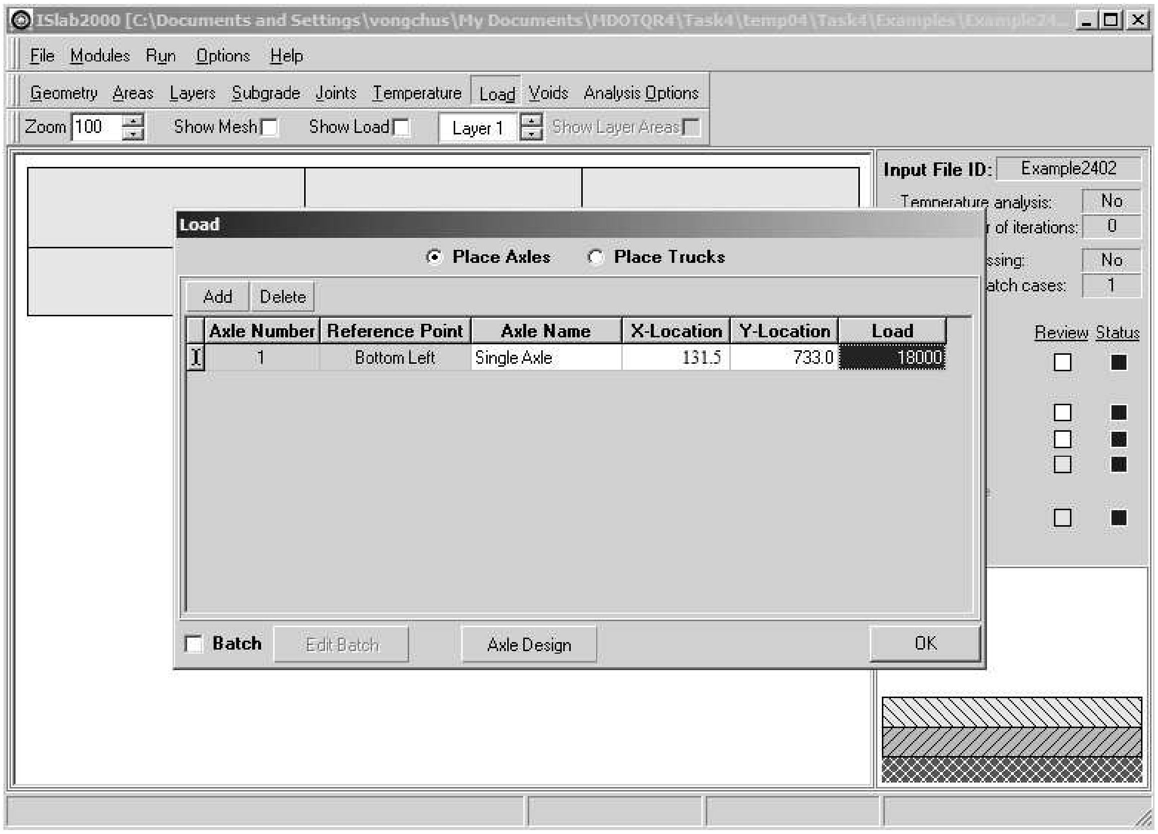


Figure E24-6: Edit Inputs for the Load Module

Temperature Module

This module is not required for this problem.

Analysis Options Module

This module is not required for this problem.

The main panel should display the pavement structure, loading condition, and meshing as shown in Figure E24-7.

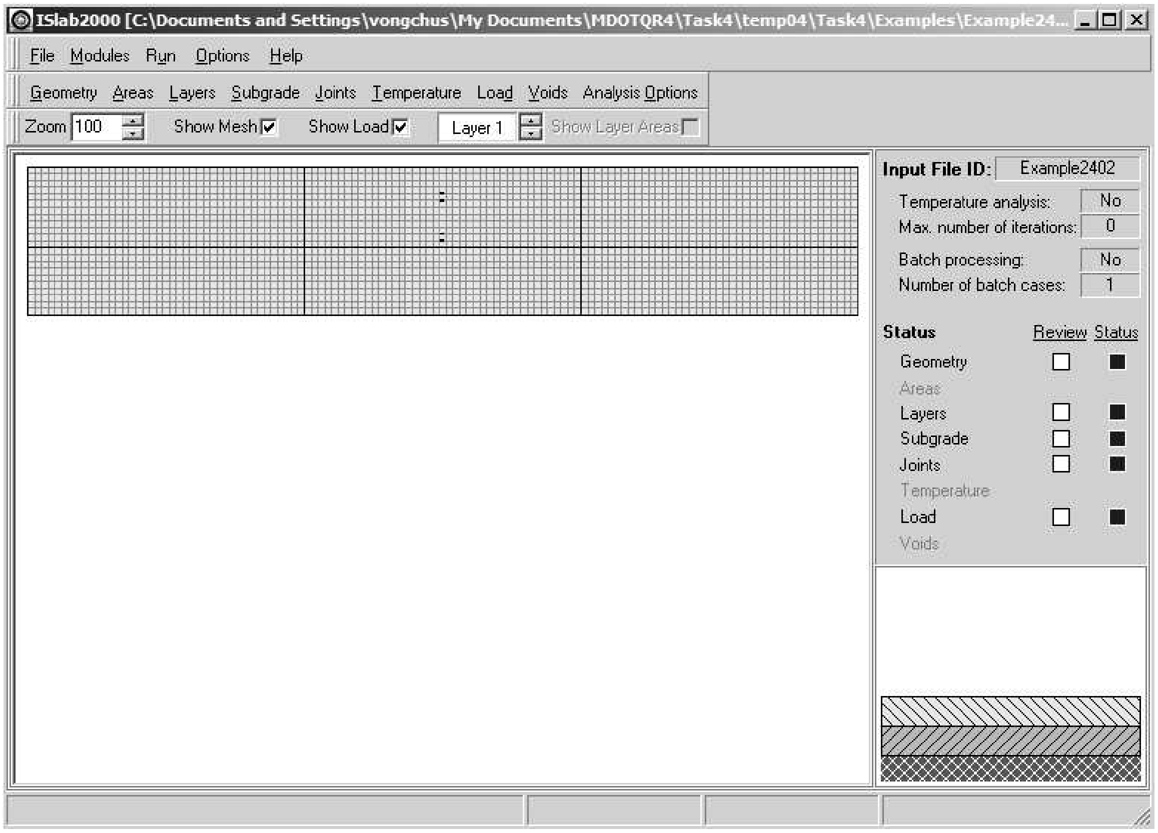


Figure E24-7: Main Panel After the Completion of Inputs (492-in. joint spacing)

Analysis Results

Joint spacing, in.	Stress at the bottom of the PCC, psi	
	Transverse	Longitudinal
180	72.1	114.5
315	72.1	107.2
492	72.1	106.7

Table E24-1: Analysis Results

NOTE
Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Stress and deflection contours from ISLAB2000 are also available in Figures E24-8 through E24-13. Figure E24-14 illustrates relationship between maximum stresses and joint spacing.

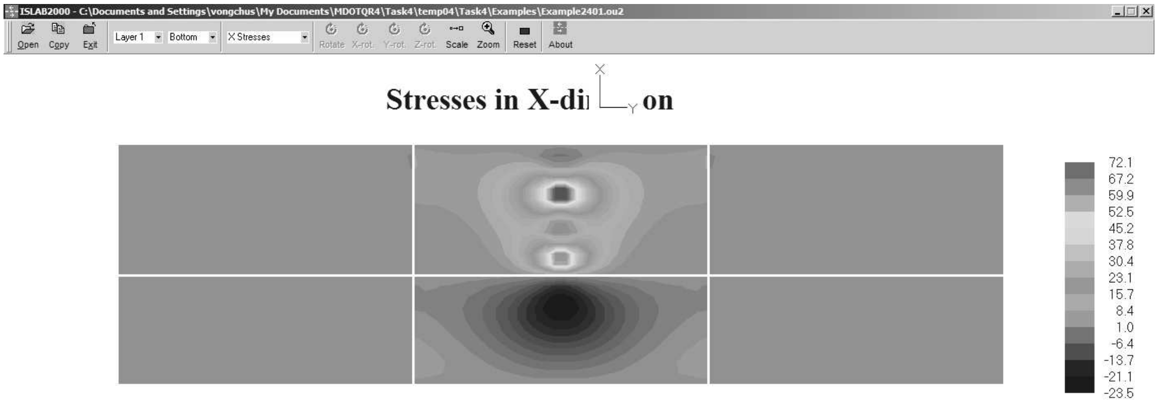


Figure E24-8: Transverse Stress at the Bottom of the PCC Slab (315-ft joint spacing)

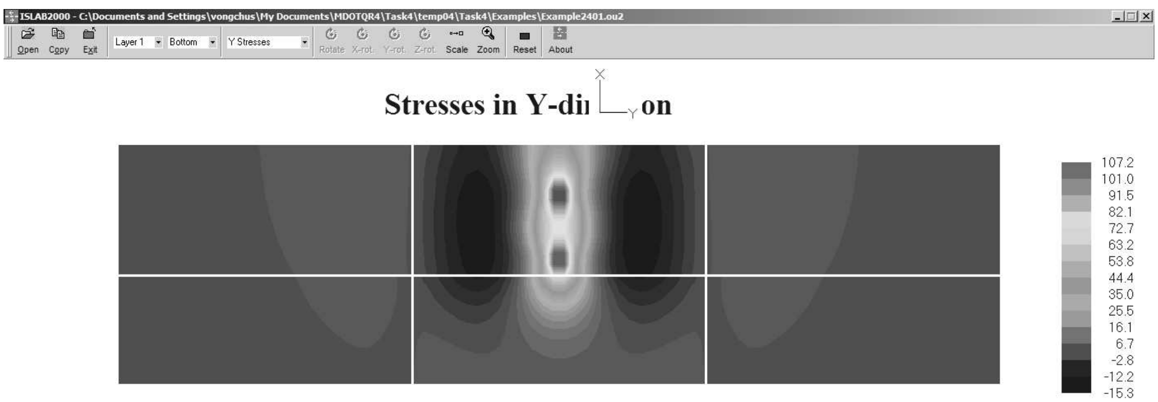


Figure E24-9: Longitudinal Stress at the Bottom of the PCC Slab (315-ft joint spacing)

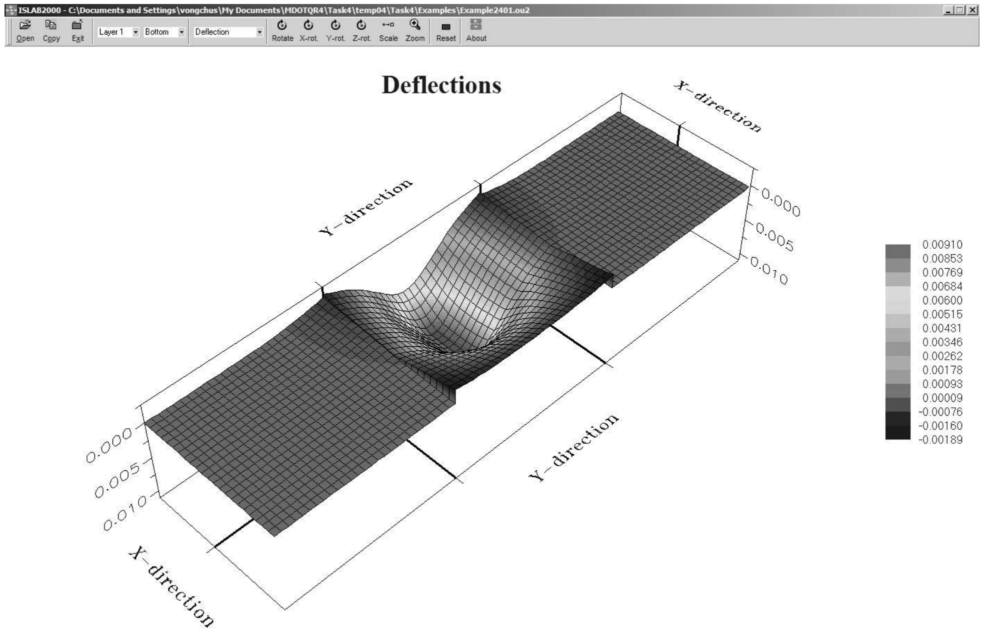


Figure E24-10: Deflection of the PCC Slab (315-ft joint spacing)

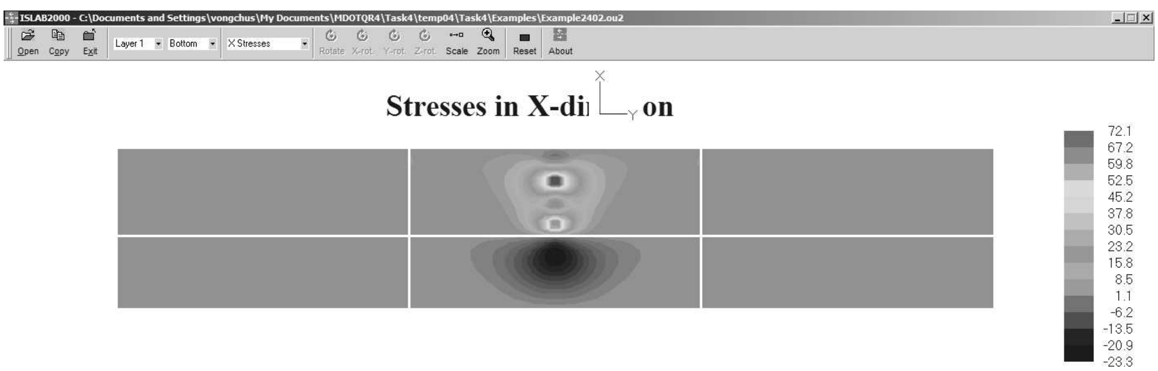


Figure E24-11: Transverse Stress at the Bottom of the PCC Slab (492-ft joint spacing)

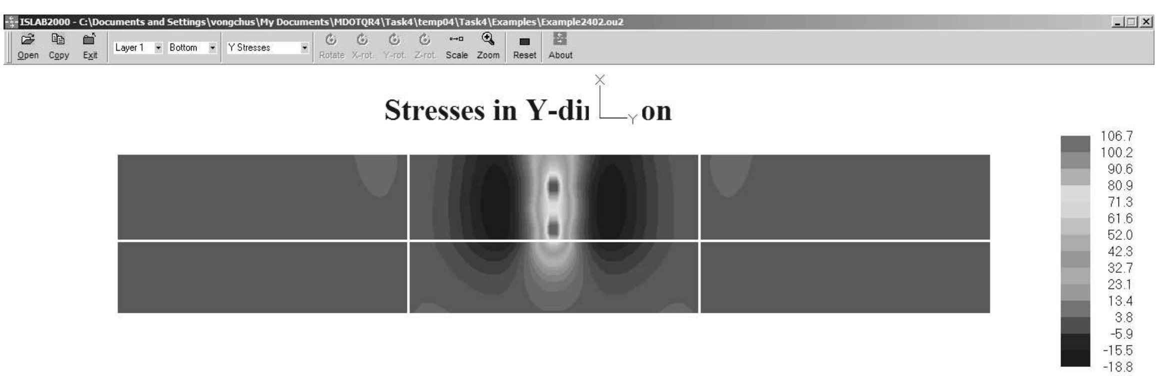


Figure E24-12: Longitudinal Stress at the Bottom of the PCC Slab (492-ft joint spacing)

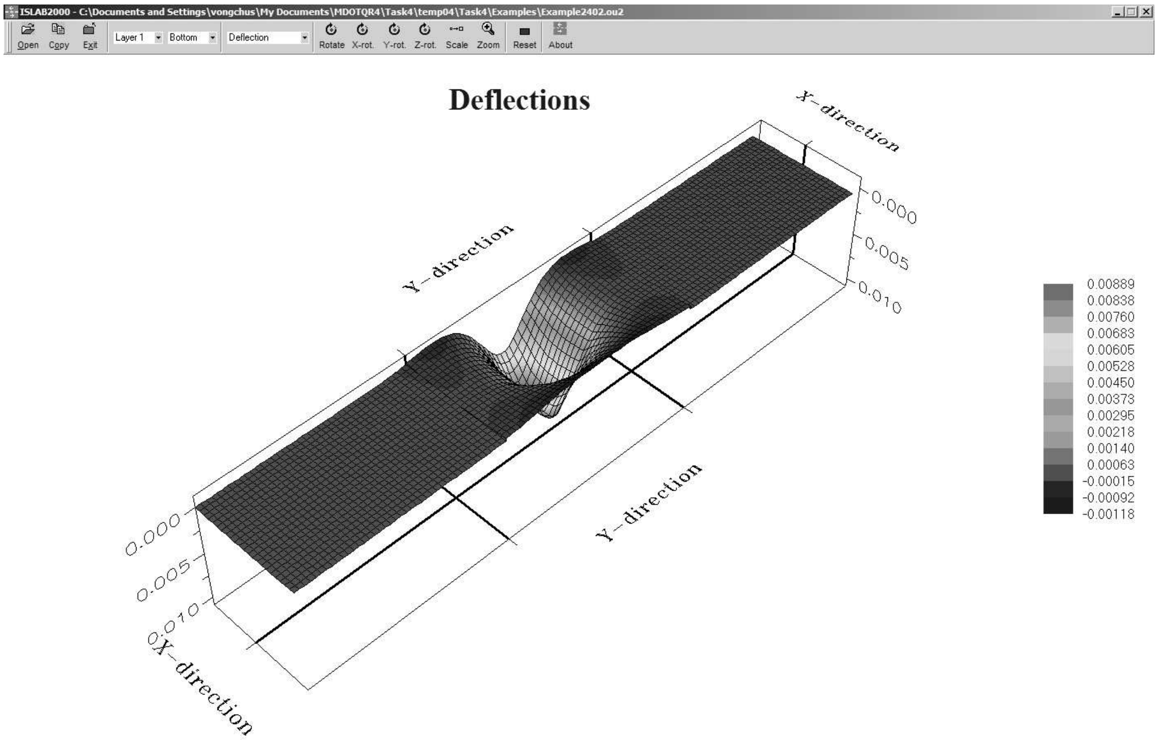


Figure E24-13: Deflection of the PCC Slab (492-ft joint spacing)

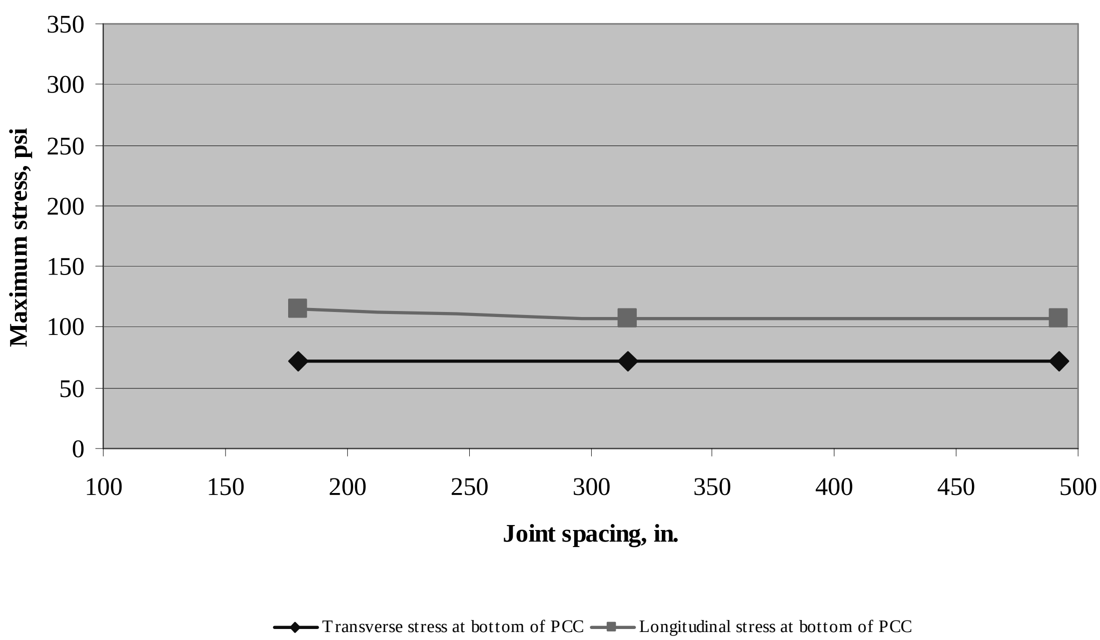


Figure E24-14: Relationship Between Maximum Stresses and Joint Spacing

Example 25:
Repeat Example 24 with a Thermal Gradient

Problem Statement

Repeat Example 24 but also apply temperature differential, ΔT, of +20 ^oF.

Given

Joint spacing	=	315, 492	in.
Temperature differential, ΔT	=	+20	^oF.

Problem Illustration

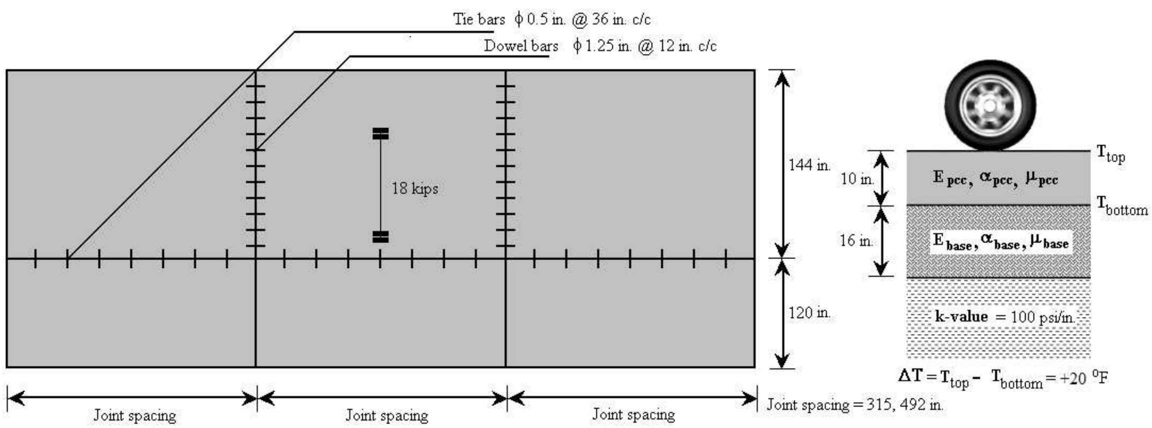


Figure E25-1: Problem Illustration

Solution

PART 1: 315-in. joint spacing

Geometry Module

Use this module from 315-ft joint spacing in Example 24.

Layers Module

Use this module from Example 8.

Subgrade Module

Use this module from Example 8.

Joints Module

Use this module from Example 8.

Load Module

Use this module from 315-ft joint spacing in Example 24.

Temperature Module

This module is not required for this problem.

Analysis Options Module

This module is not required for this problem.

The main panel should display the pavement structure, loading condition, and meshing as shown in Example 24, Figure E24-4.

PART 2: 492-in. joint spacing

Geometry Module

Use this module from 492-ft joint spacing in Example 24.

Layers Module

Use this module from Example 8.

Subgrade Module

Use this module from Example 8.

Joints Module

Use this module from Example 8.

Load Module

Use this module from 492-ft joint spacing in Example 24.

Temperature Module

This module is not required for this problem.

Analysis Options Module

This module is not required for this problem.

The main panel should display the pavement structure, loading condition, and meshing as shown in Example 24, Figure E24-7.

Analysis Results

Joint spacing, in.	Stress at the bottom of the PCC, psi	
	Transverse	Longitudinal
180	139.7	224.5
315	145.0	325.8
492	140.2	326.2

Table E25-1: Analysis Results

NOTE
Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Stress and deflection contours from ISLAB2000 are also available in Figures E25-2 through E25-7. Figure E25-8 illustrates relationship between maximum stresses and joint spacing.

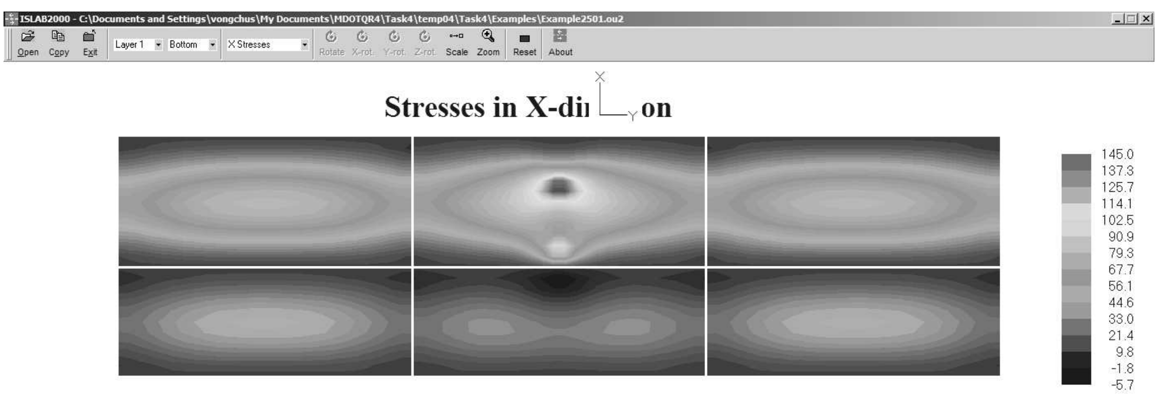


Figure E25-2: Transverse Stress at the Bottom of the PCC Slab (315-ft joint spacing)

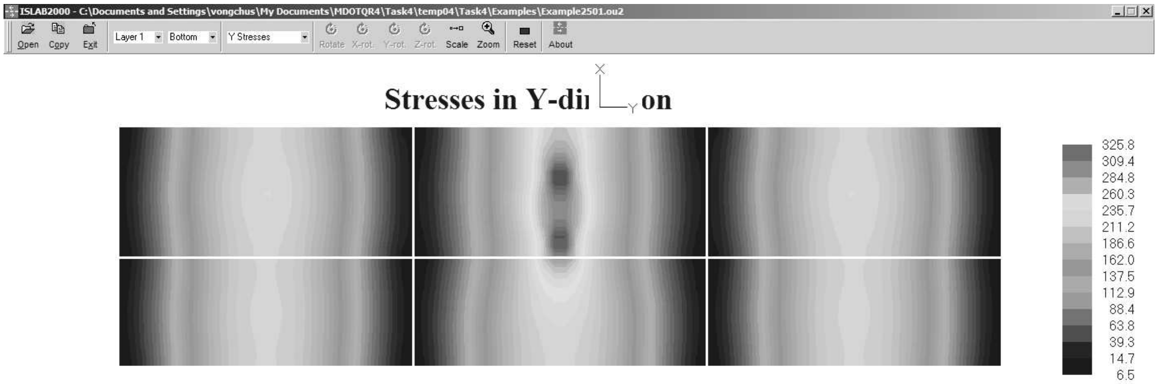


Figure E25-3: Longitudinal Stress at the Bottom of the PCC Slab (315-ft joint spacing)

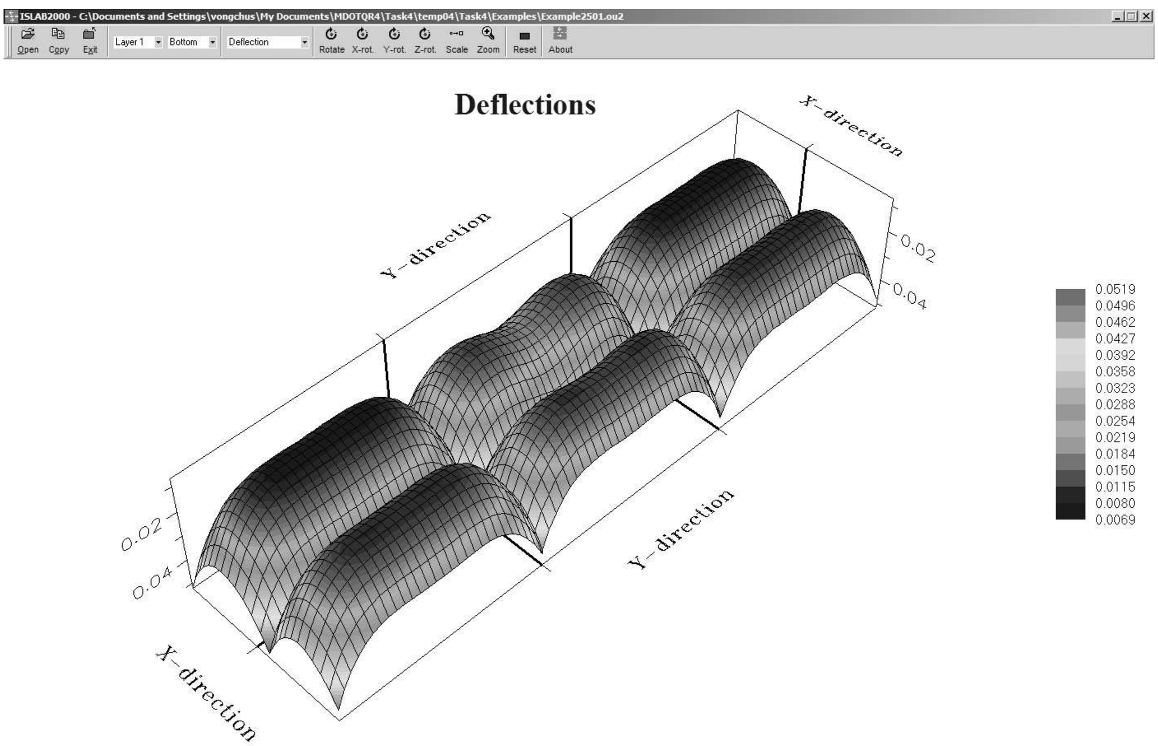


Figure E25-4: Deflection of the PCC Slab (315-ft joint spacing)

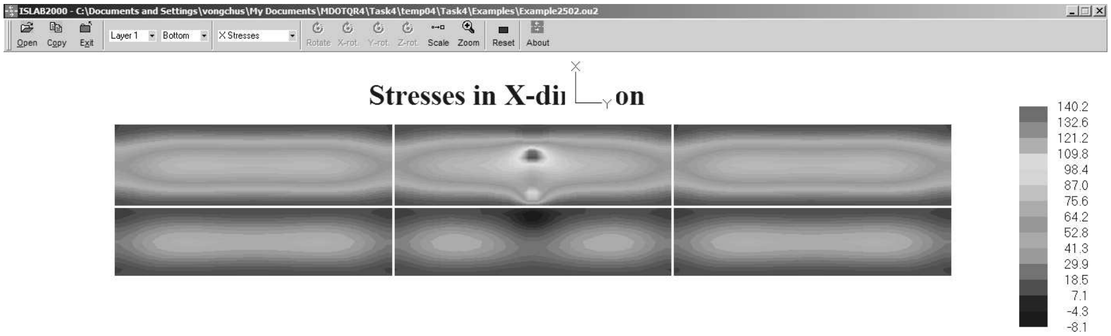


Figure E25-5: Transverse Stress at the Bottom of the PCC Slab (492-ft joint spacing)

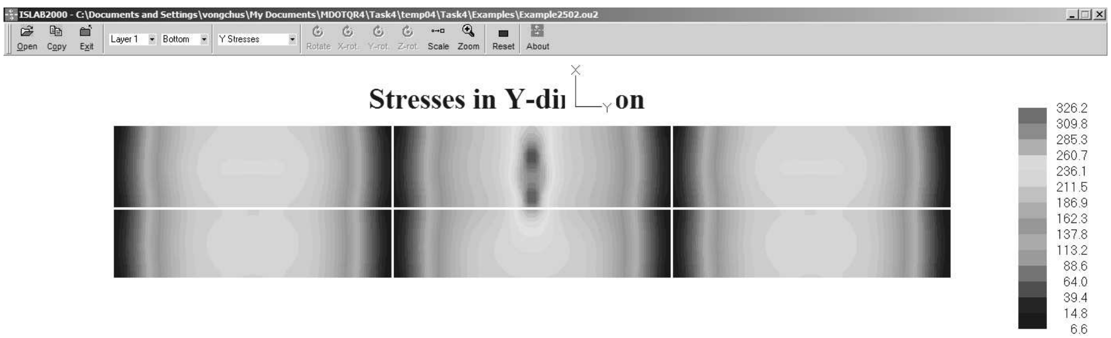


Figure E25-6: Longitudinal Stress at the Bottom of the PCC Slab (492-ft joint spacing)

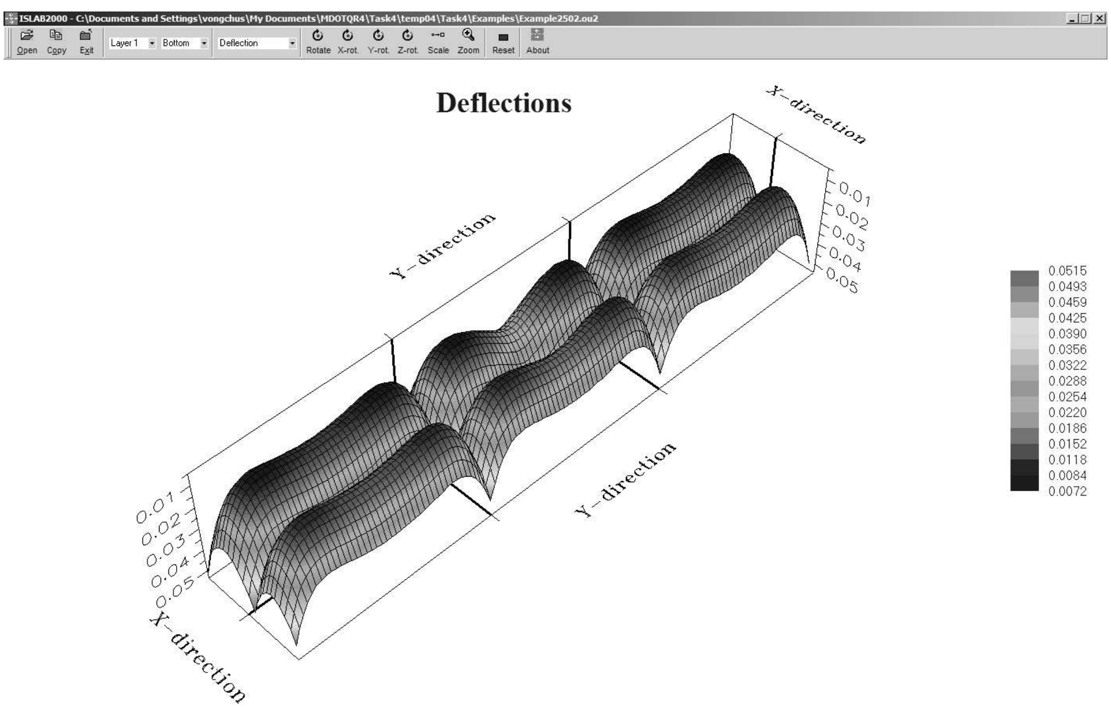


Figure E25-7: Deflection of the PCC Slab (492-ft joint spacing)

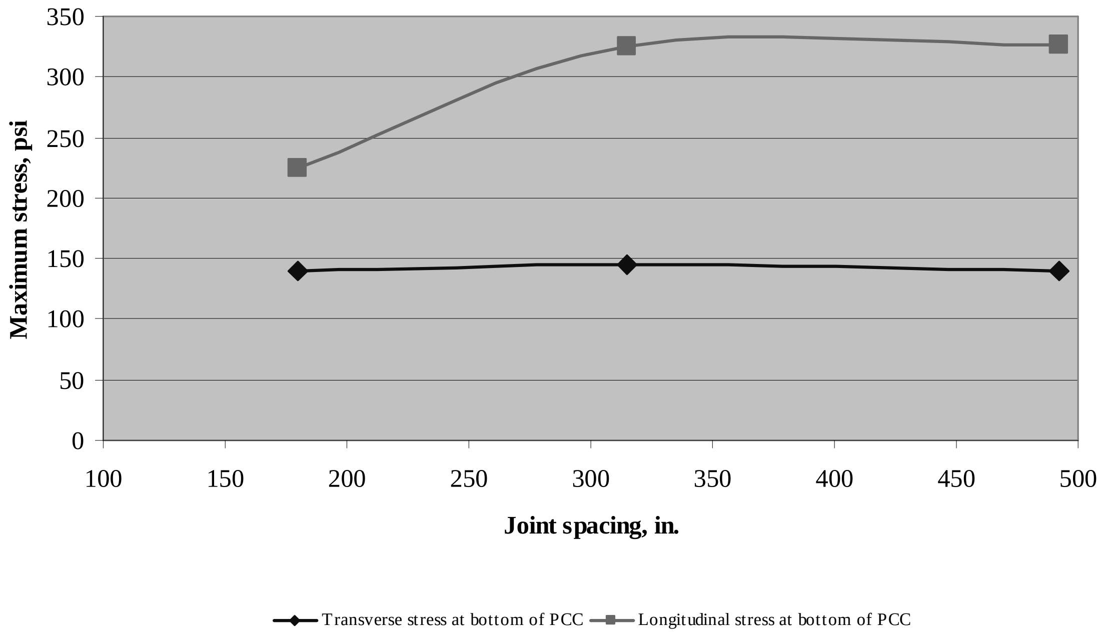


Figure E25-8: Relationship Between Maximum Stresses and Joint Spacing

Example 26:
Full-depth PCC Patch, 4 Feet Wide

Problem Statement

Analyze the pavement system in Example 8, but also consider a 4-ft wide full-depth PCC patch in the middle of the lane.

Given

Patch elastic modulus	=	3×10^6	psi
Patch Poisson's ratio	=	0.15	
Patch coefficient of thermal exp	=	7×10^{-6}	in./in./^{o}F

Problem Illustration

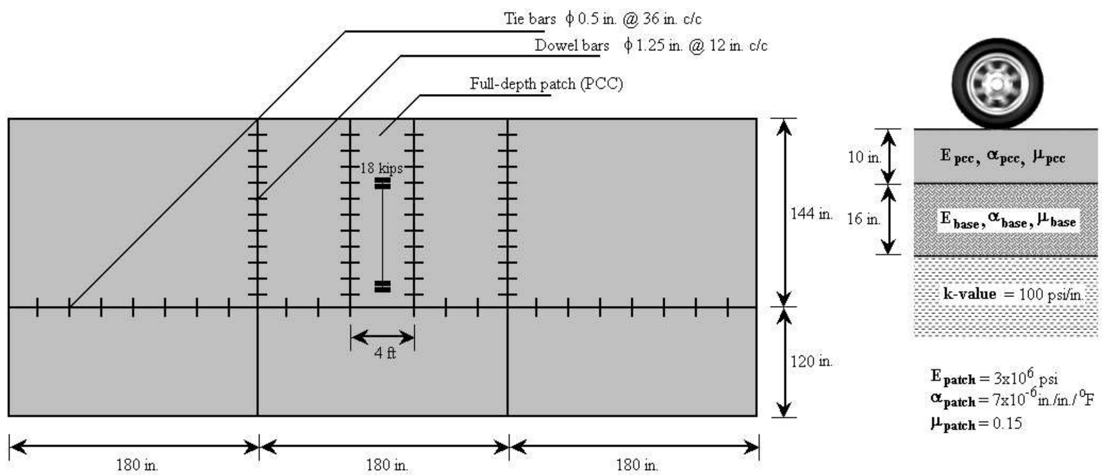


Figure E26-1: Problem Illustration

Solution

Geometry Module

(see Figure E26-2)

Step 1: Click **Geometry** to open the geometry panel.

Step 2: On the geometry panel, click **Insert** two times on the **X-direction** side to insert two additional slabs, and then enter the shoulder width (120 inches) and the lane width (144 inches) in the **Length** field for each slab.

Step 3: Click **Insert** five times on the **Y-direction** side to insert five additional slabs, and then enter the **180**, **66**, **48**, **66**, and **180** in the **Length** field for each slab.

Step 4: On the right side of the geometry panel, select **Medium** to set the mesh size.

Step 5: Click **Generate** to generate the inputs to the input file, and then click **OK** to close the geometry panel.

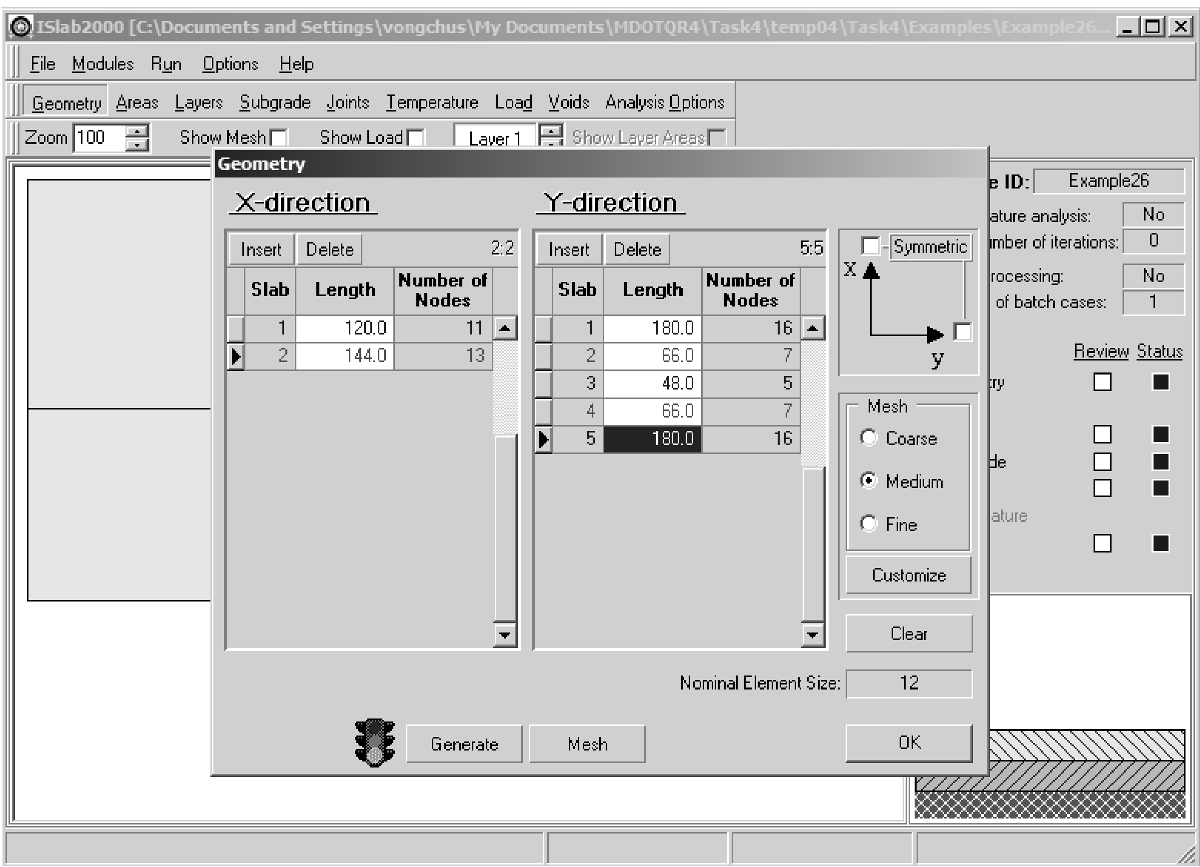


Figure E26-2: Edit Inputs for the Geometry Module

Area Module

(see Figure E26-3)

Step 1: Click **Area** to open the area definition panel, and then click **Add** and enter **Patch** in the **Area Name** field.

Step 2: Select **Coordinates** in the **Coordinate Type** field.

Step 3: Enter the coordinate for the shoulder area as identified in the problem illustration.

Step 4: Click **OK** to close the area definition panel.

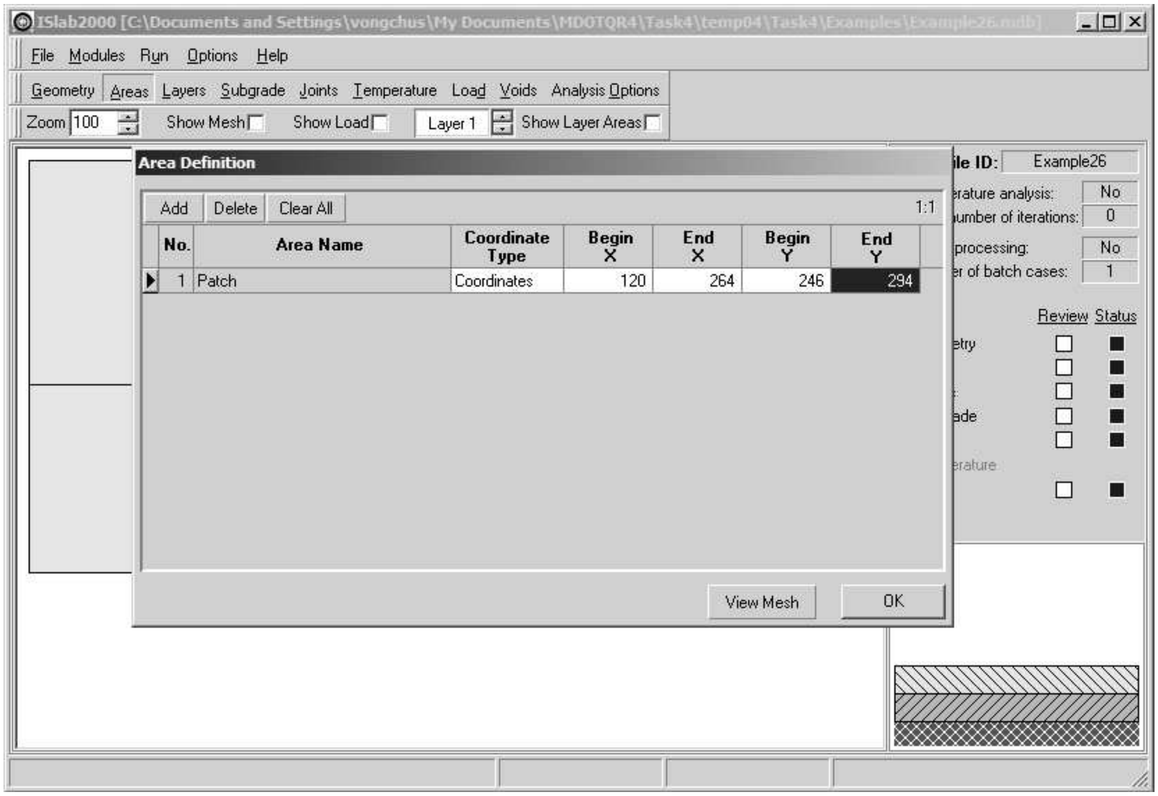


Figure E26-3: Edit Inputs for the Area Module

Layers Module

(see Figure E26-4)

Step 1: Follow steps 1 through 4 of this module in Example 8.

Step 2: On Layer 1, select **Exception**, and then click **Edit Exception** to open the exception properties panel for layer 1.

Step 3: Click **Insert**, and then select **Patch** in the **Area Name** field.

Step 4: Enter the material properties for patch material as shown in Figure E26-4.

Step 5: Click **OK** to close the layers panel.

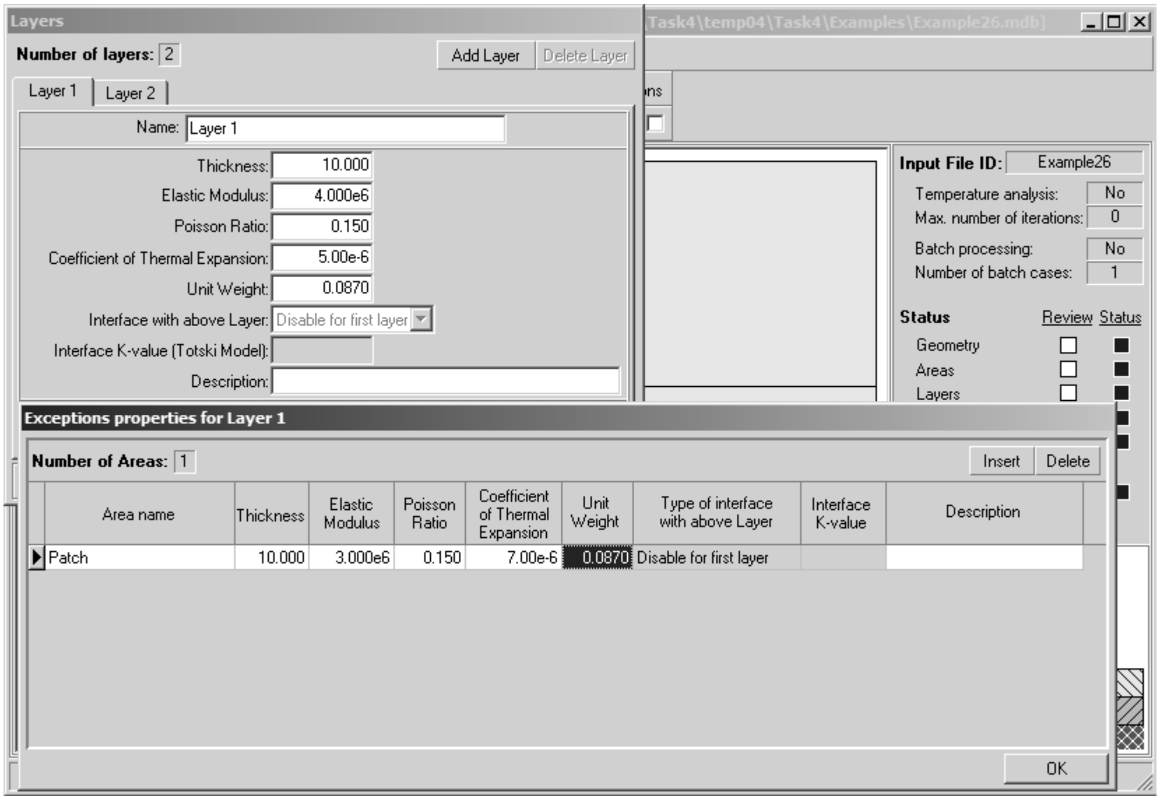


Figure E26-4: Edit Inputs for the Layer Module

Subgrade Module

Use this module from Example 8.

Joints Module

Use this module from Example 8.

Load Module

Use this module from Example 8.

Temperature Module

Temperature module is not required for this problem.

Analysis Options Module

This module is not required for this problem.

The main panel should display the pavement structure, loading condition, and meshing as shown in Figure E26-5.

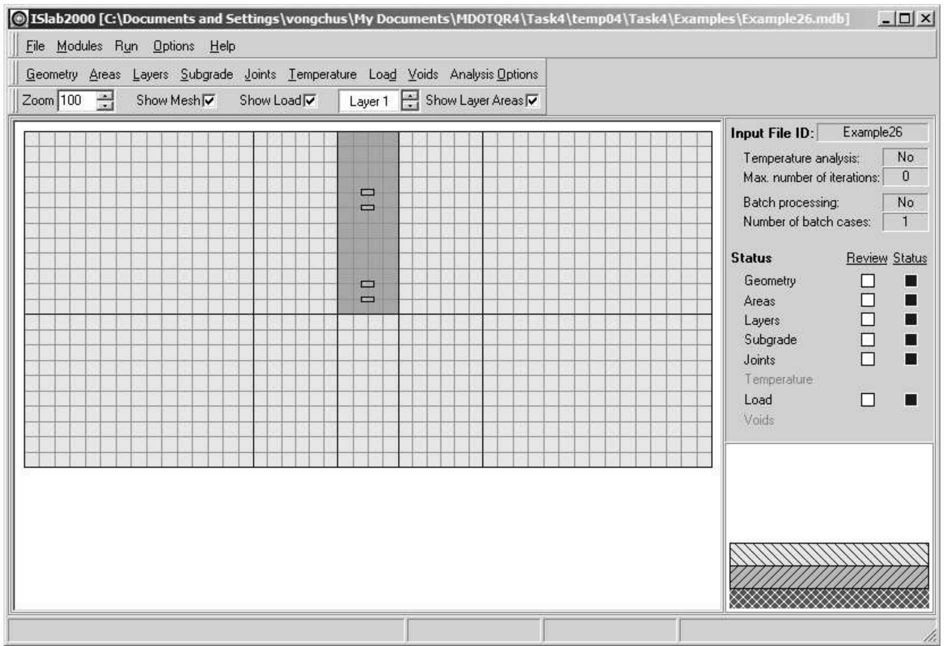


Figure E26-5: Main Panel After the Completion of Inputs

Analysis Results

Maximum transverse stress at the bottom of the PCC slab = 87.6 psi (see Figure E26-6)

Maximum longitudinal stress at the bottom of the PCC slab = 91.5 psi (see Figure E26-7)

NOTE

Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Stress and deflection contours from ISLAB2000 are also available in Figures E26-6 through E26-8.

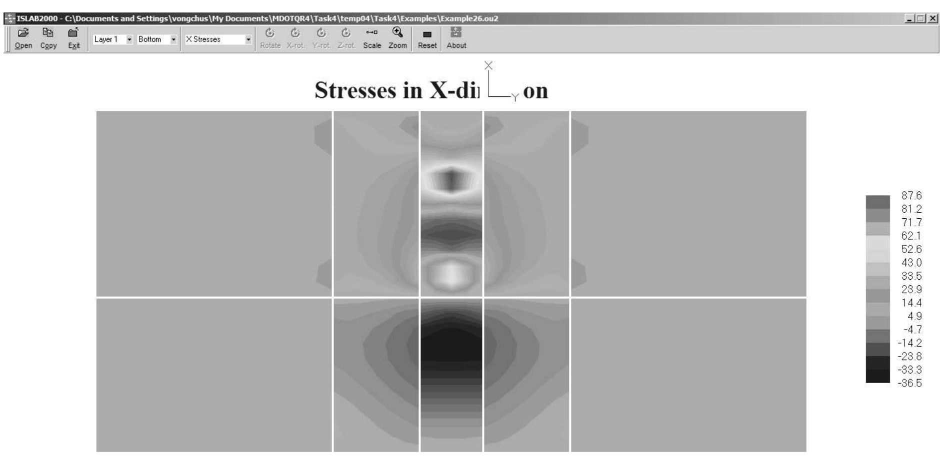


Figure E26-6: Transverse Stress at the Bottom of the PCC Slab

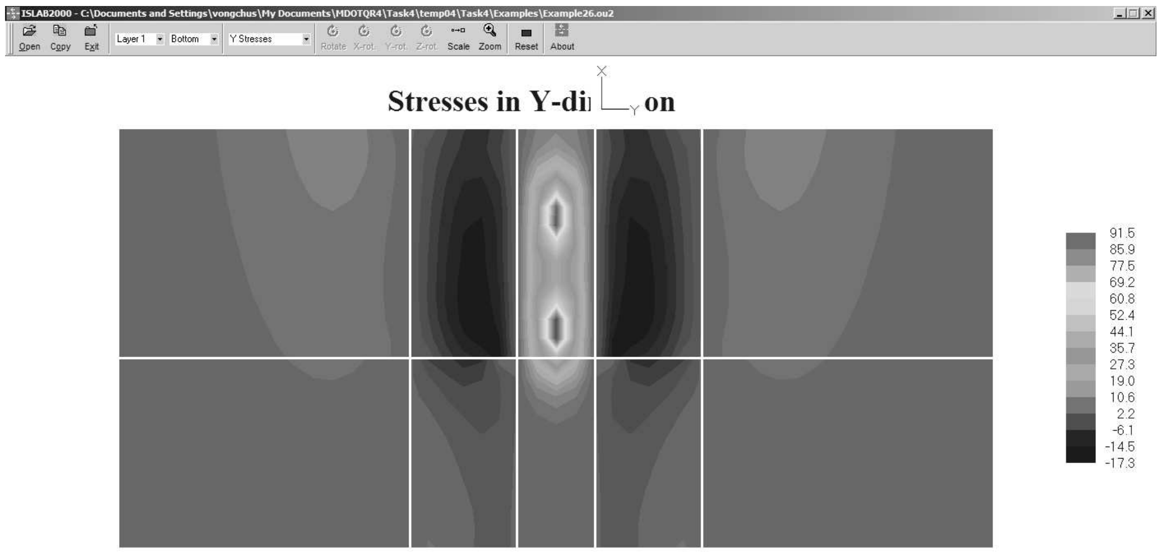


Figure E26-7: Longitudinal Stress at the Bottom of the PCC Slab

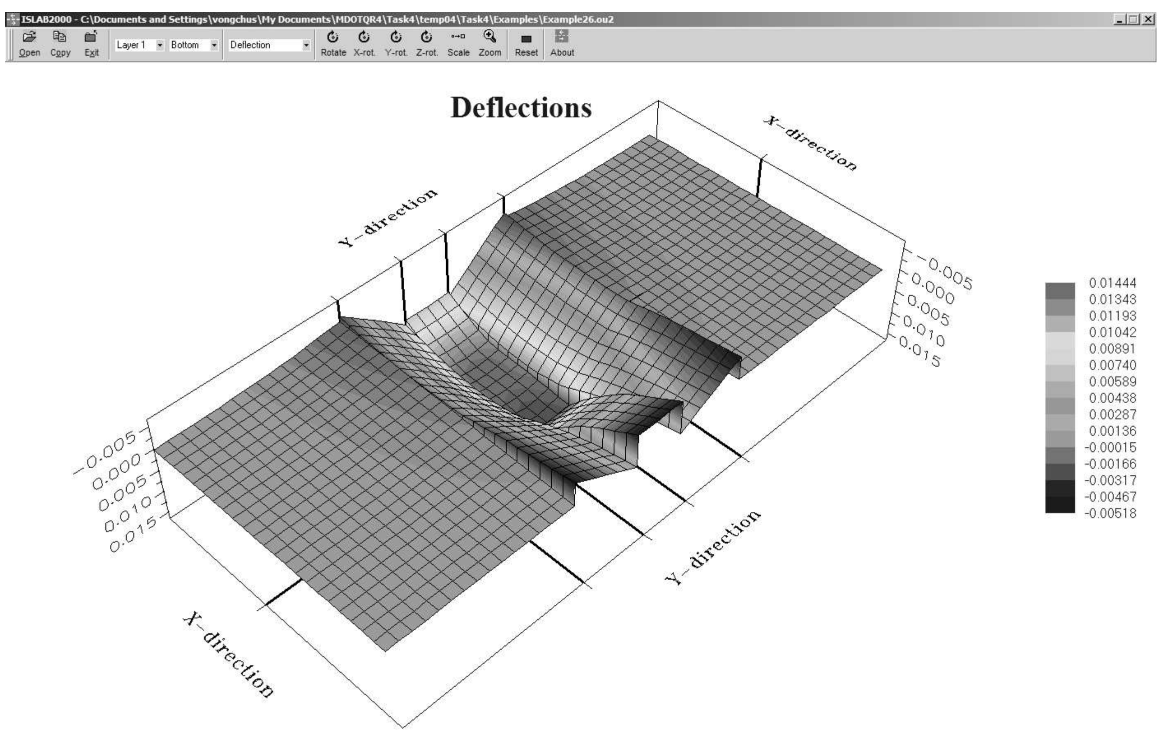


Figure E26-8: Deflection of the PCC Slab

Example 27:
Full Depth PCC Patch. 6 Feet Wide

Problem Statement

Analyze a pavement system with a full-depth PCC patch similar to Example 26, but consider 315-in. joint spacing and a 6-ft wide full-depth PCC patch in the middle of the lane.

Given

Patch elastic modulus	=	3×10^6	psi
Patch Poisson's ratio	=	0.15	
Patch coefficient of thermal exp	=	7×10^{-6}	in./in./^{o}F

Problem Illustration

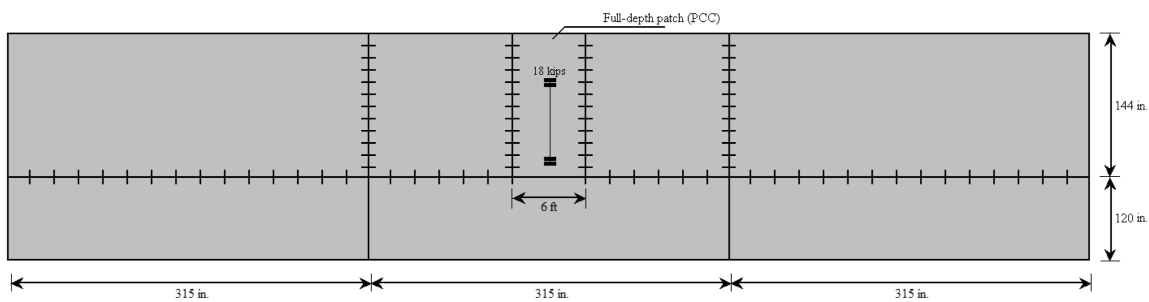


Figure E27-1: Problem Illustration

Solution

Geometry Module

(see Figure E27-2)

Step 1: Click **Geometry** to open the geometry panel.

Step 2: On the geometry panel, click **Insert** two times on the **X-direction** side to add two additional slabs, and then enter the shoulder width (120 inches) and the lane width (144 inches) in the length field for each slab.

Step 3: Click **Insert** five times on the **Y-direction** side to add five additional slabs, and then enter **315**, **121.5**, **72**, **121.5**, **315** in the **Length** field for each slab.

Step 4: On right hand side of the geometry panel, select **Medium** to set the mesh size.

Step 5: Click **Generate** to generate the inputs to the input file, and then click **OK** to close the geometry panel.

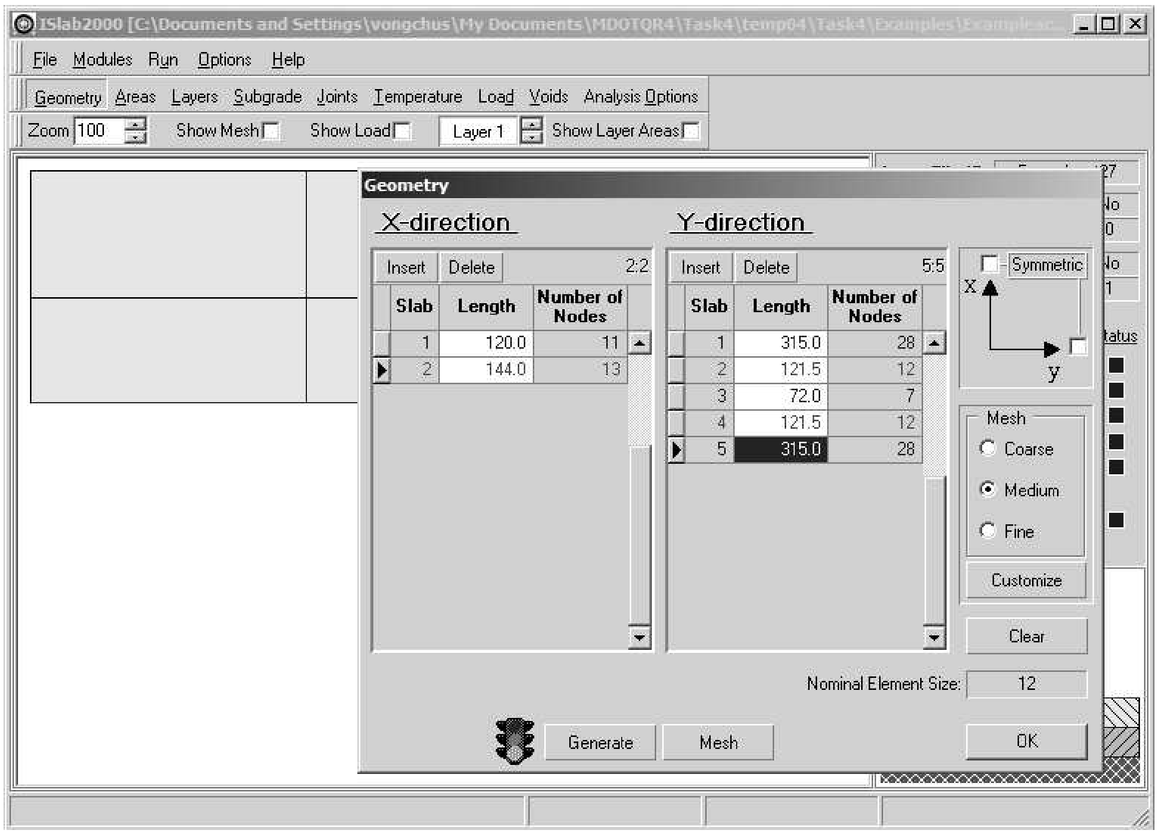


Figure E27-2: Edit Inputs for the Geometry Module

Area Module

(see Figure E27-3)

Step 1: Click **Area** to open the area definition panel, and then click **Add** and enter **Patch** in the **Area Name** field.

Step 2: Select **Coordinates** in the **Coordinate type** field.

Step 3: Enter the coordinate for the shoulder area as identified in the problem illustration.

Step 4: Click **OK** to close the area definition panel.

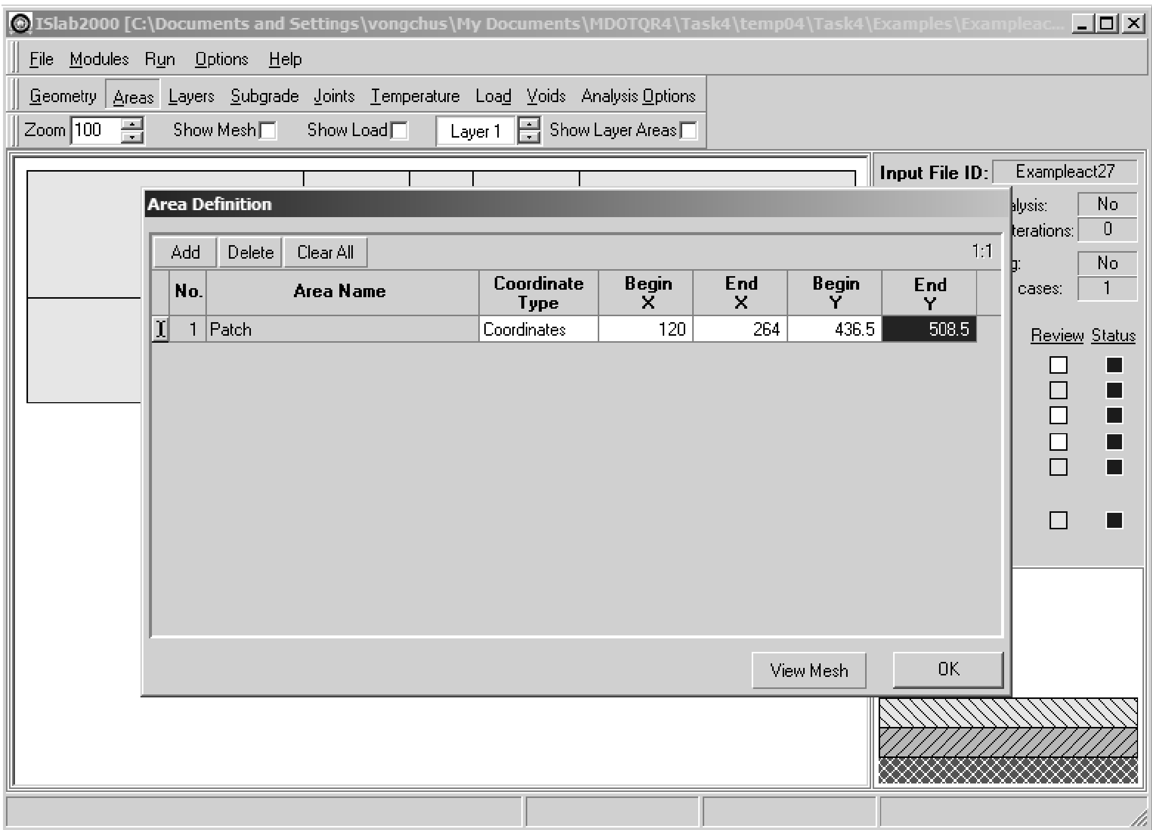


Figure E27-3: Edit Inputs for the Area Module

Layers Module

(see Figure E27-4)

Step 1: Follow steps 1 through 4 of this module in Example 8.

Step 2: On Layer 1, select **Exception** and click **Edit Exception** to open the exception properties panel for layer 1.

Step 3: Click **Insert**, and then select **Patch** in the Are name field.

Step 4: Enter the material properties for patch material as shown in Figure E27-4.

Step 5: Click **OK** to close the layers panel.

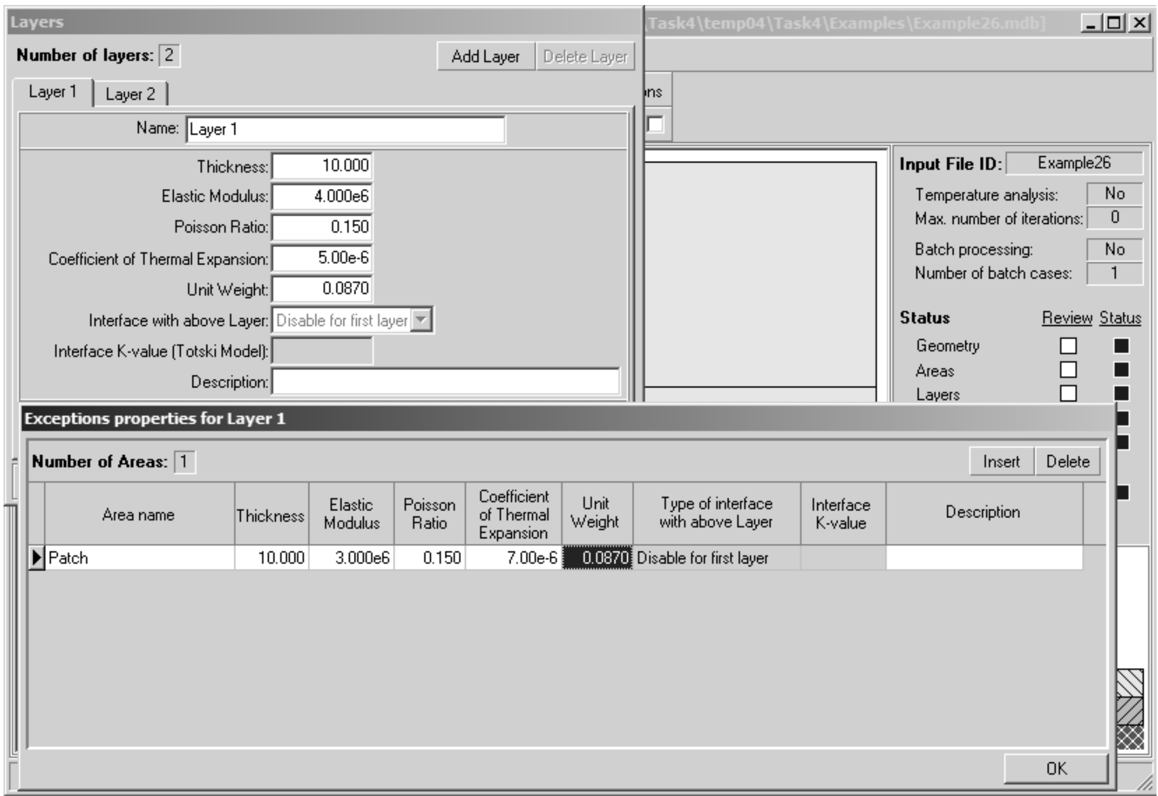


Figure E27-4: Edit Inputs for the Layer Module

Subgrade Module

Use this module from Example 8.

Joints Module

Use this module from Example 8.

Load Module

Use this module from Example 8.

Temperature Module

Temperature module is not required for this problem.

Analysis Options Module

This module is not required for this problem.

The main panel should display the pavement structure, loading condition, and meshing as shown in Figure E27-5.

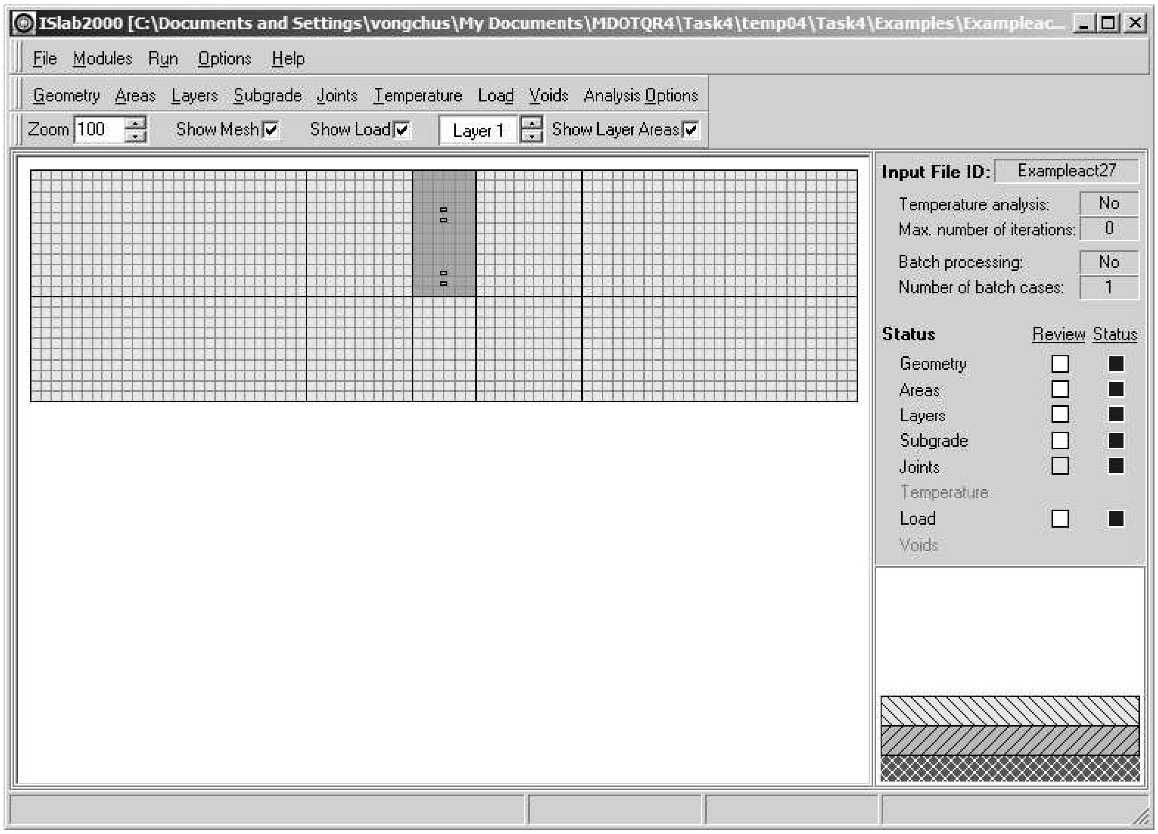


Figure E27-5: Main Panel After the Completion of Inputs

Analysis Results

Maximum transverse stress at the bottom of the PCC slab = 83.7 psi (see Figure E27-6)

Maximum longitudinal stress at the bottom of the PCC slab = 114.3 psi (see Figure E27-7)

NOTE
Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Stress and deflection contours from ISLAB2000 are also available in Figures E27-6 through E27-8.

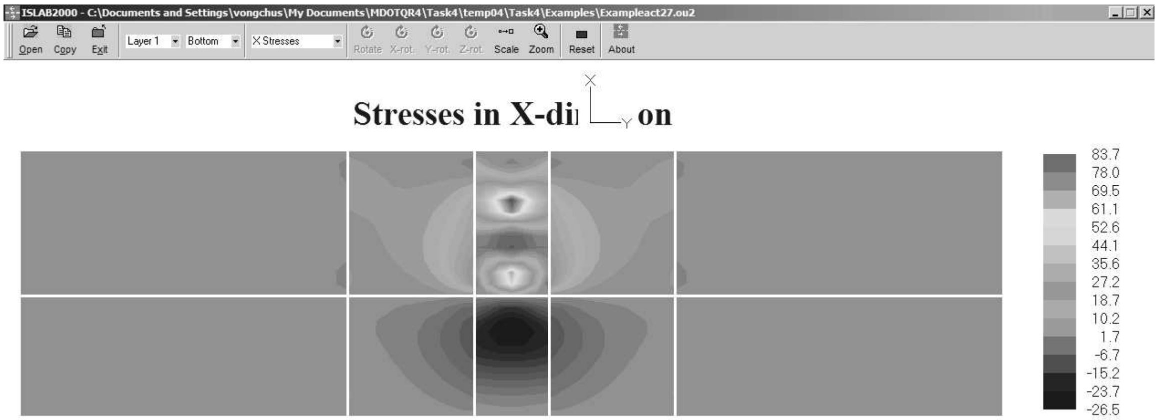


Figure E27-6: Transverse Stress at the Bottom of the PCC Slab

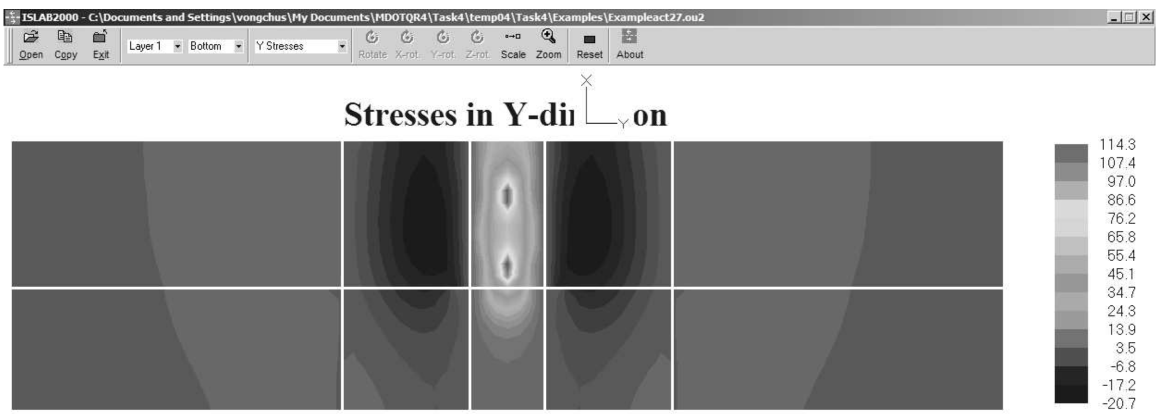


Figure E27-7: Longitudinal Stress at the Bottom of the PCC Slab

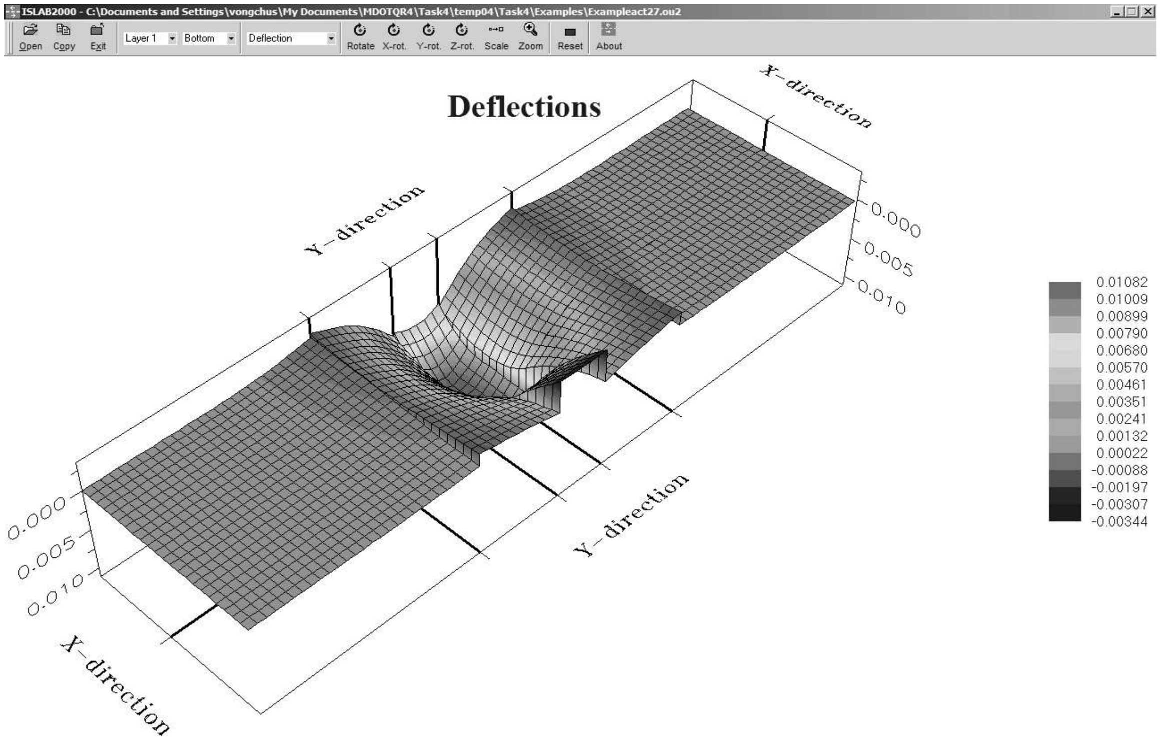


Figure E27-8: Deflection of the PCC Slab

Example 28:
Full-depth AC Patch

Problem Statement

Analyze the pavement system in Example 8, but also consider a 4-ft wide full-depth AC patch at the middle of the lane.

Given

Patch elastic modulus	=	3×10^5	psi
Patch Poisson's ratio	=	0.35	
Patch coefficient of thermal exp	=	2×10^{-6}	in./in./^oF

Problem Illustration

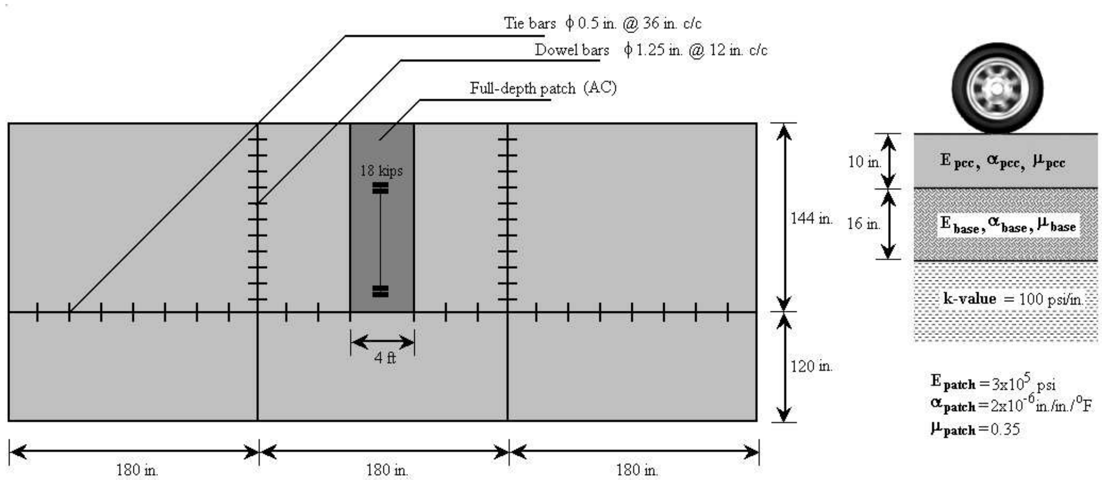


Figure E28-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 26.

Area Module

Use this module from Example 26.

Layers Module

(see Figure E28-2)

Step 1: Follow steps 1 through 4 of this module in Example 8.

Step 2: On Layer 1, select **Exception**, and then click **Edit Exception** to open the exception properties panel for layer 1.

Step 3: Click **Insert**, and then select **Patch** in the area **Name** field.

Step 4: Enter the material properties for patch material as shown in Figure E28-2.

Step 5: Click **OK** to close the layers panel.

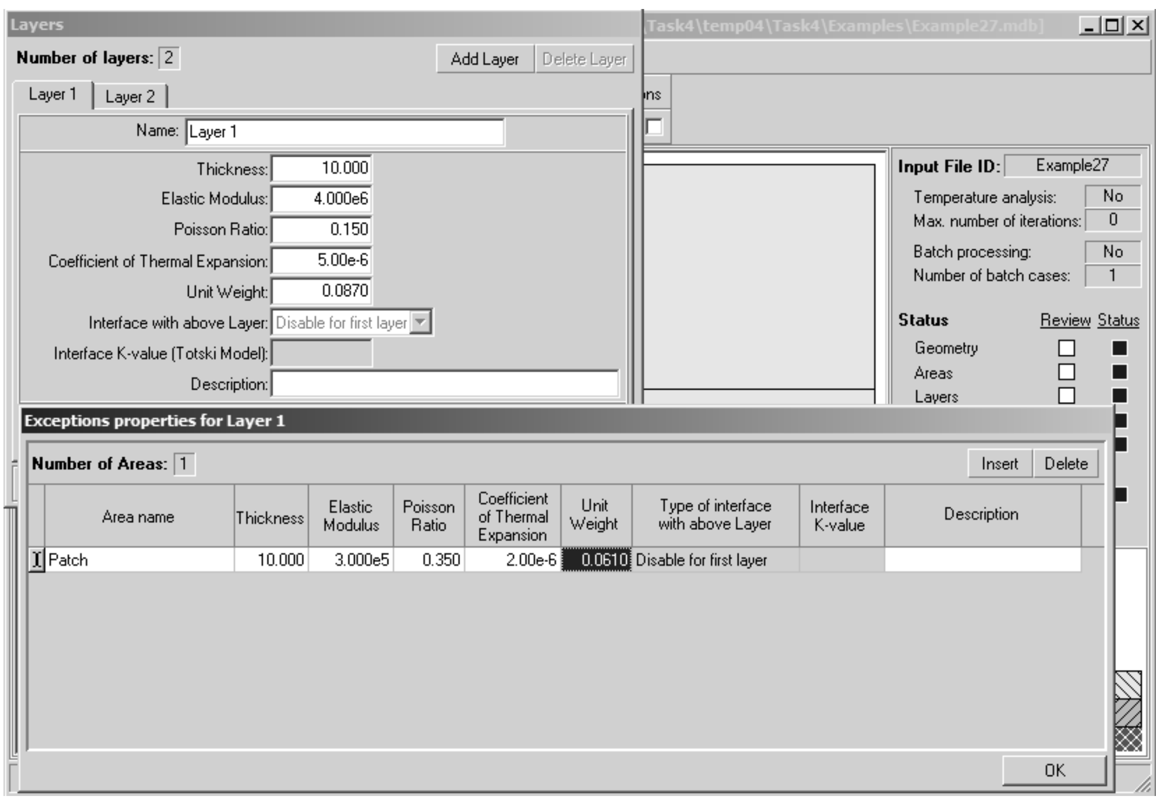


Figure E28-2: Edit Inputs for the Layer Module

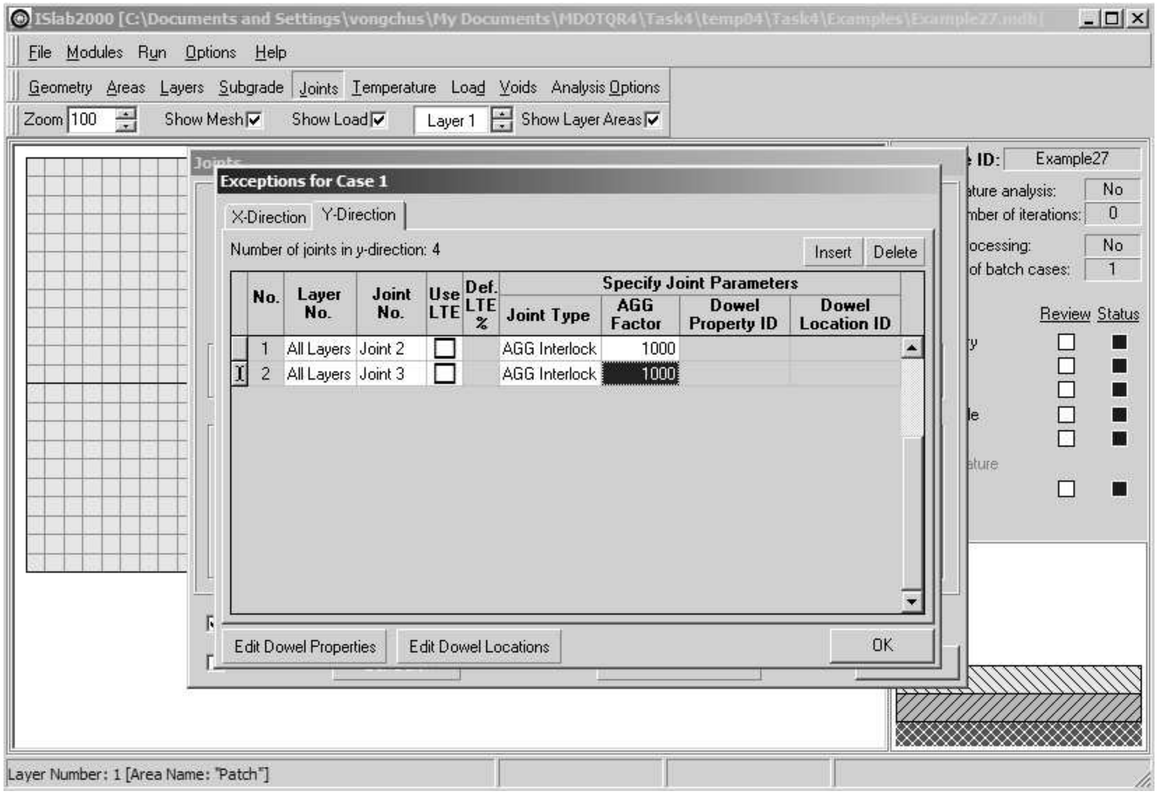


Figure E28-3: Edit Inputs for the Joints Module

Subgrade Module

Use this module from Example 8.

Joints Module

(see Figure E28-3)

Step 1: Follow steps 1 through 5 of this module in Example 8, but do not click on **OK** to close the joints panel.

Step 2: Select **Exceptions** and click Edit Exception to open the exception panel for case 1.

Step 3: Click **Insert** two times to add two additional joints. For No. 1, select **Joint 2**, **AGG Interlock,** and then enter **1000** for the AGG Factor. Do the same for No. 2 for Joint 3.

Load Module

Use this module from Example 8.

Temperature Module

Temperature module is not required for this problem.

Analysis Options Module

This module is not required for this problem.

The main panel should display the pavement structure, loading condition, and meshing as shown in Example 26, Figure E26-5.

Analysis Results

Maximum transverse stress at the bottom of the PCC slab = 64.5 psi (see Figure E28-4)

Maximum longitudinal stress at the bottom of the PCC slab = 64.8 psi (see Figure E28-5)

> **NOTE**
> Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Stress and deflection contours from ISLAB2000 are also available in Figures E28-4 through E28-5.

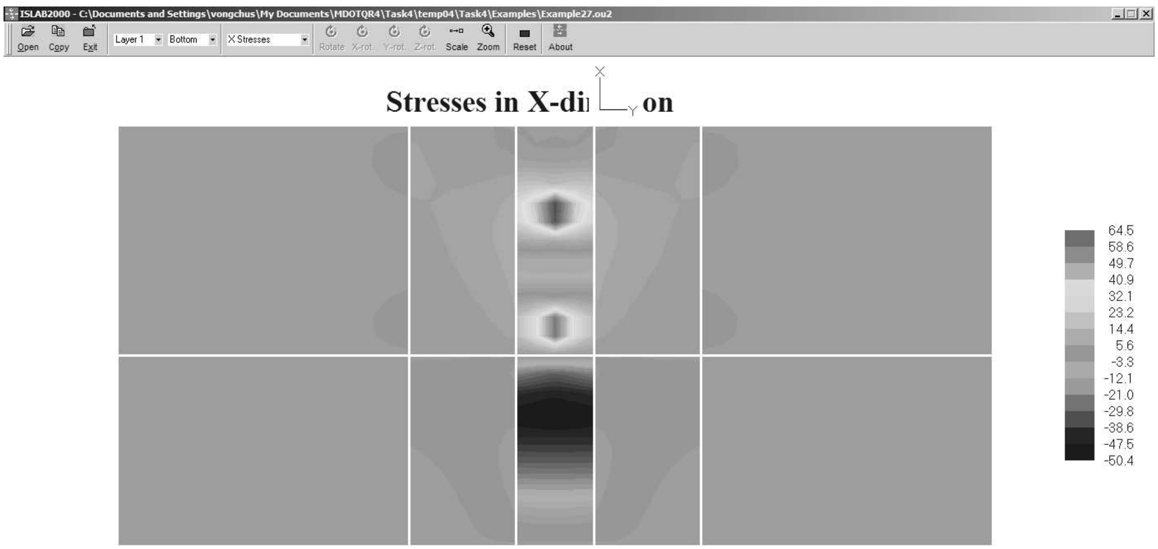


Figure E28-4: Transverse Stress at the Bottom of the PCC Slab

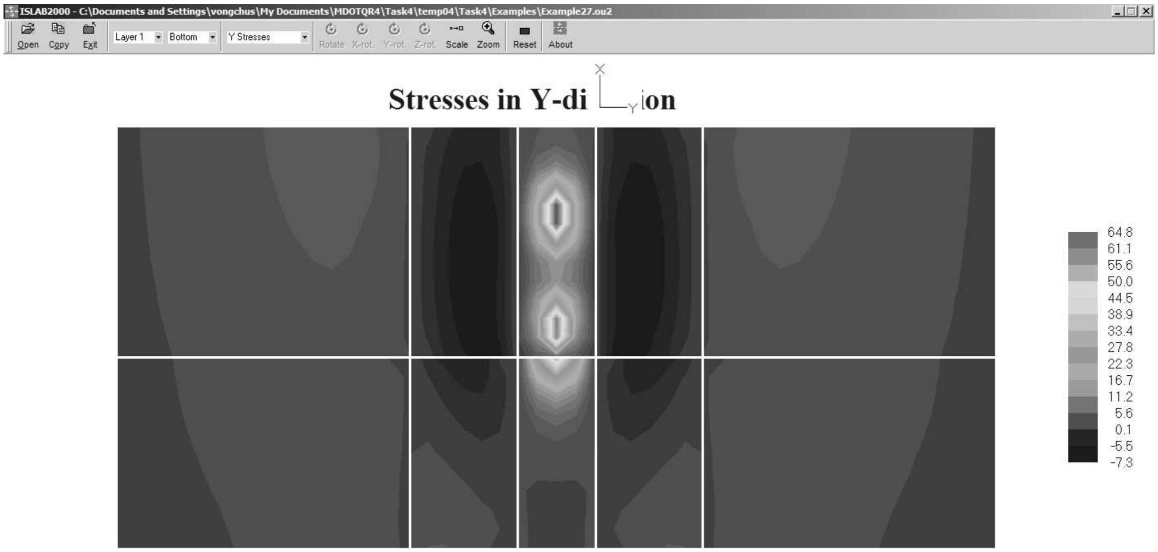


Figure E28-5: Longitudinal Stress at the Bottom of the PCC Slab

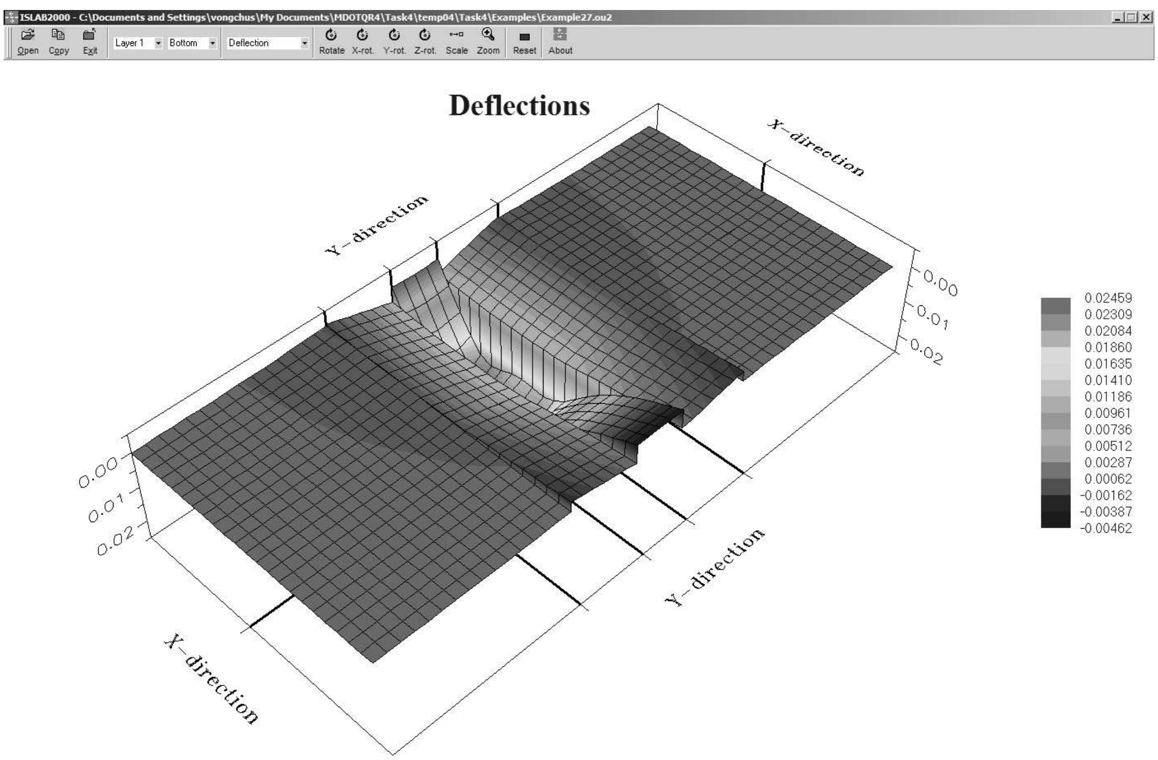


Figure E28-6: Deflection of the PCC Slab

Example 29:
Void at Slab Corner

Problem Statement

Determine maximum tresses at the top of the PCC slab for the pavement system in Example 8, but also consider void potential at the slab corner as illustrated in Figure E29-1. Then, compare the results with the results from no void potential case, as in Example 10.

Given

Void potential area = 2 x 2 ft^2

Problem Illustration

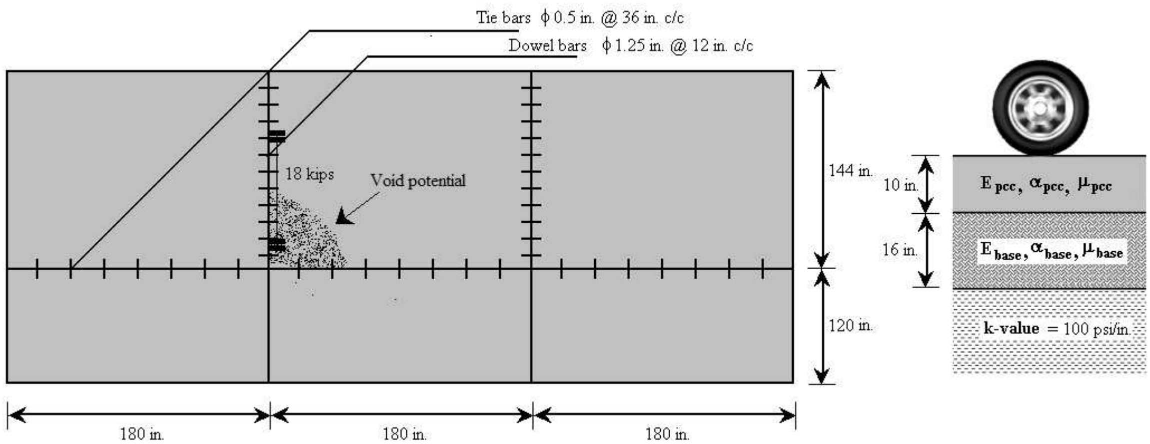


Figure E29-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 8.

Area Module

(see Figure E29-2)

Step 1: Click **Area** to open the area module, click on **Add** to open the area definition panel, and then enter **Void** in the **Area Name** field.

Step 2: Select **Coordinates** in the **Coordinate type** field.

Step 3: Enter the coordinate for the shoulder area as identified in the problem illustration.

Step 4: Click **OK** to close the area definition panel.

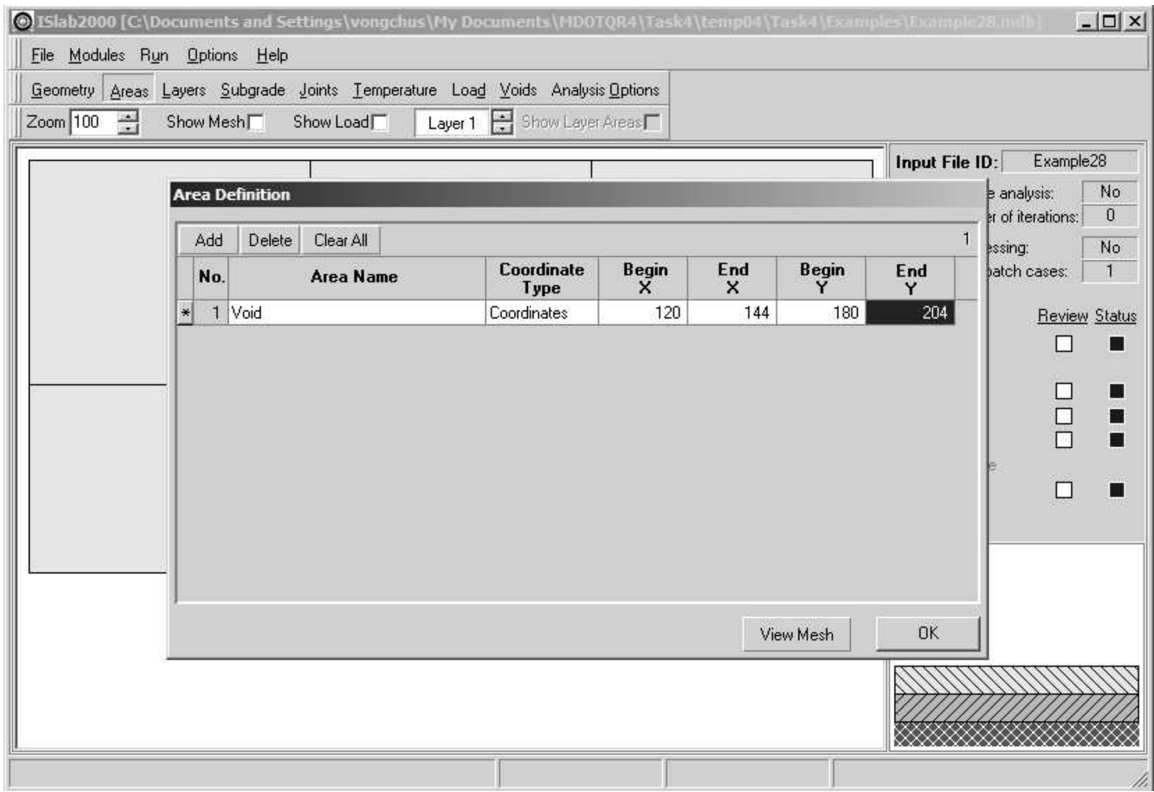


Figure E29-2: Edit Inputs for the Area Module

Layers Module

Use this module from Example 8.

Subgrade Module

(see Figure E29-3)

Step 1: Click **Layers** to open the layers panel.

Step 2: On the layers panel, enter the inputs as identified in the problem statement.

Step 3: Select **Exceptions**, click on **Edit Exception** to open the exceptions properties for subgrade panel, and then add the area **Void** and type 0.01 for k-value. Click **OK** to close the exceptions properties for subgrade panel

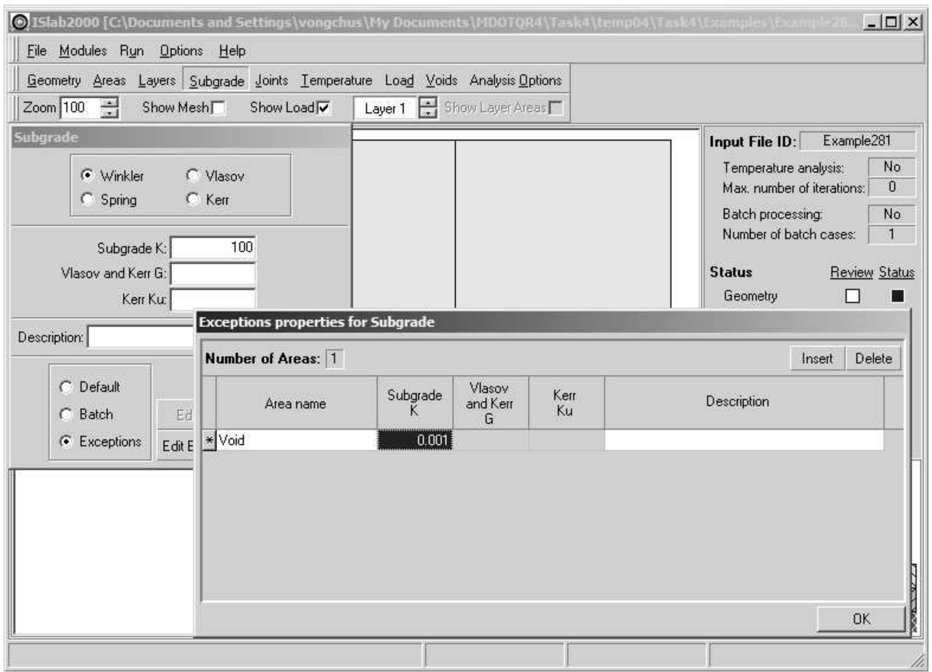


Figure E29-3: Edit Inputs for the Subgrade Module

Joints Module

Use this module from Example 8.

Load Module

Use this module from Example 10.

Temperature Module

This module is not required for the problem.

Analysis Options Module

This module is not required for this problem.

The main panel should display the pavement structure, loading condition, and meshing as shown in Figure E29-4.

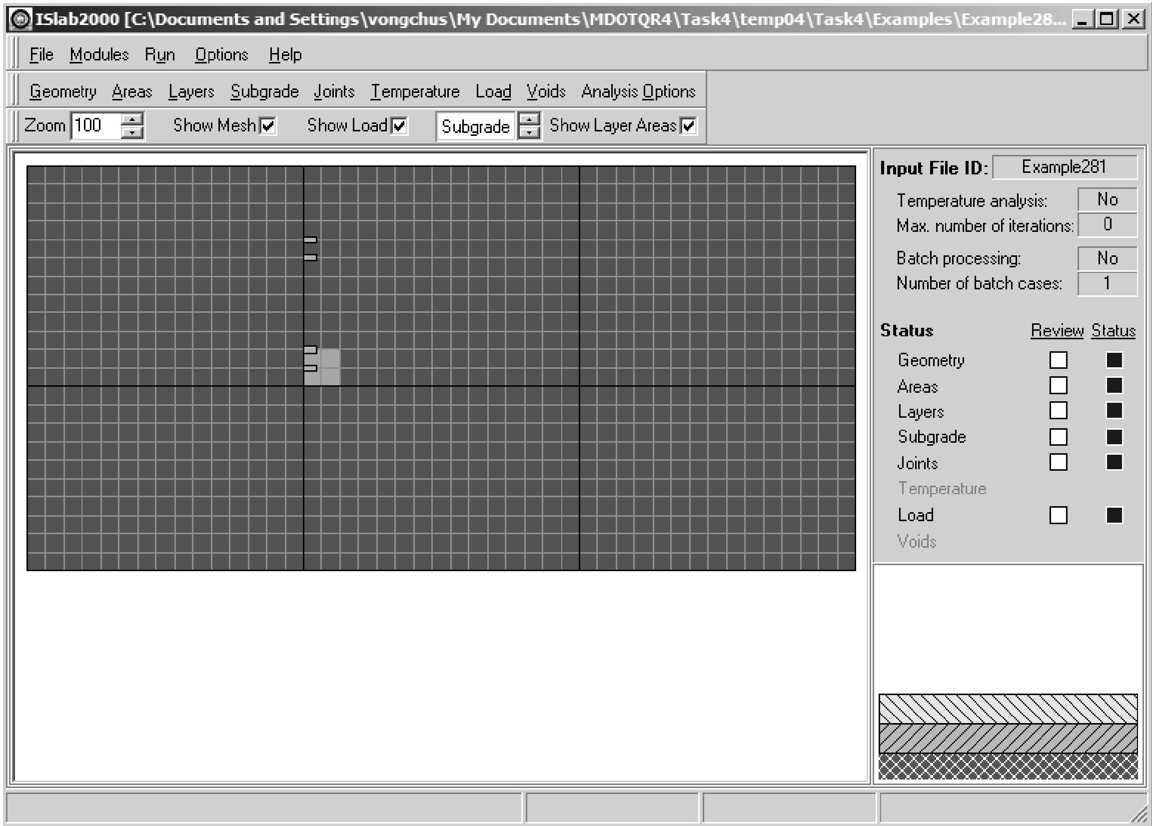


Figure E29-4: Main Panel After the Completion of Inputs

Analysis Results

Stress type	Without void potential (Example 10)	With void potential (Example 29)
Corner deflection	0.03512	0.03935
Transverse stress at top of PCC	38.9	52.1
Longitudinal stress at top of PCC	47.5	51.8

Table E29-1: Analysis Results

NOTE
Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

ISLAB2000 stress and deflection contours are also available in Figures E29-5 through E29-7. Comparison of the results between with and without void potential is shown in Figure E29-8.

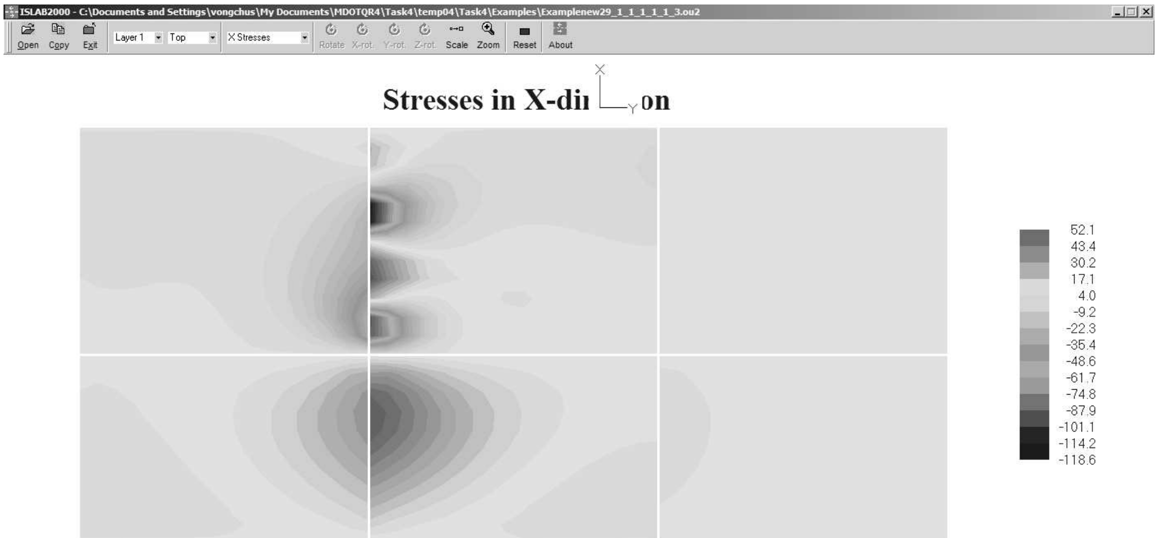


Figure E29-5: Transverse Stress at the Top of the PCC Slab

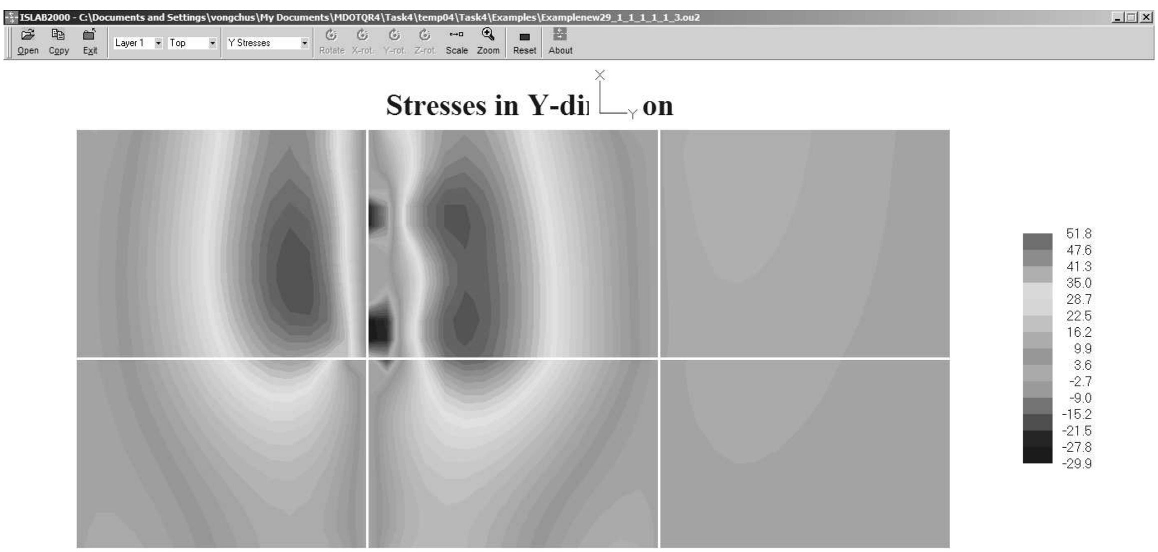


Figure E29-6: Longitudinal Stress at the Top of the PCC Slab

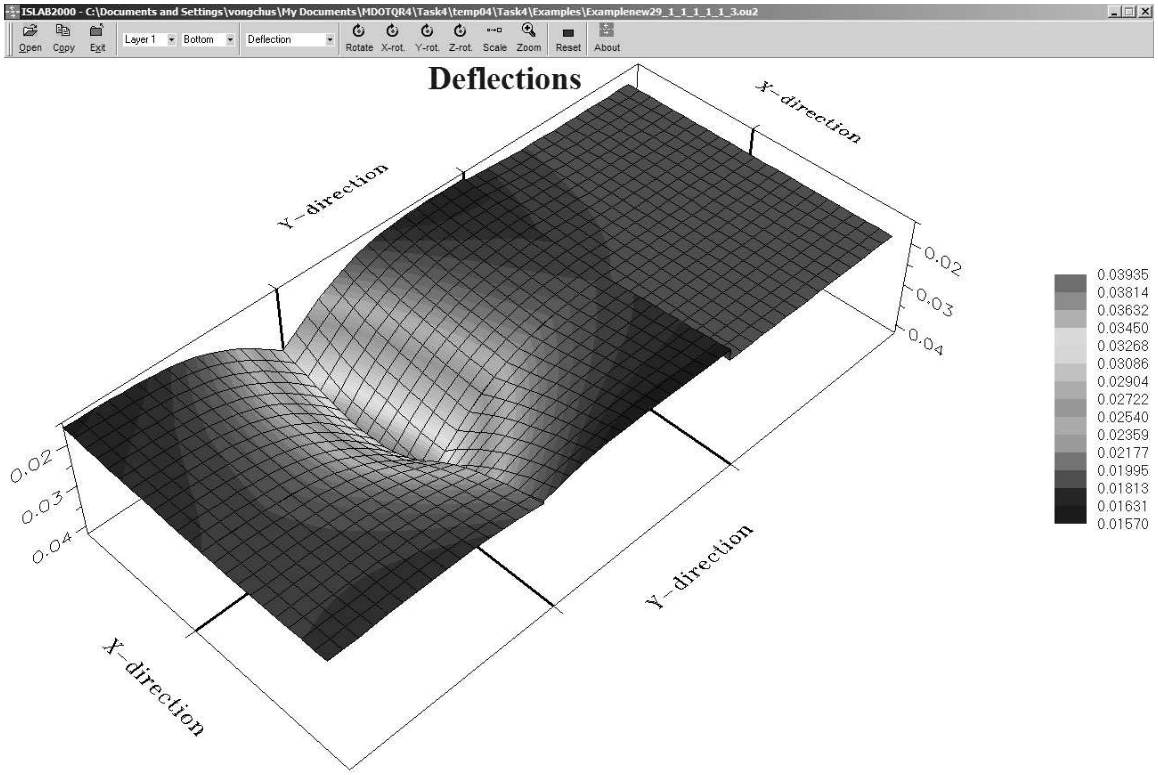


Figure E29-7: Deflection of the PCC Slab

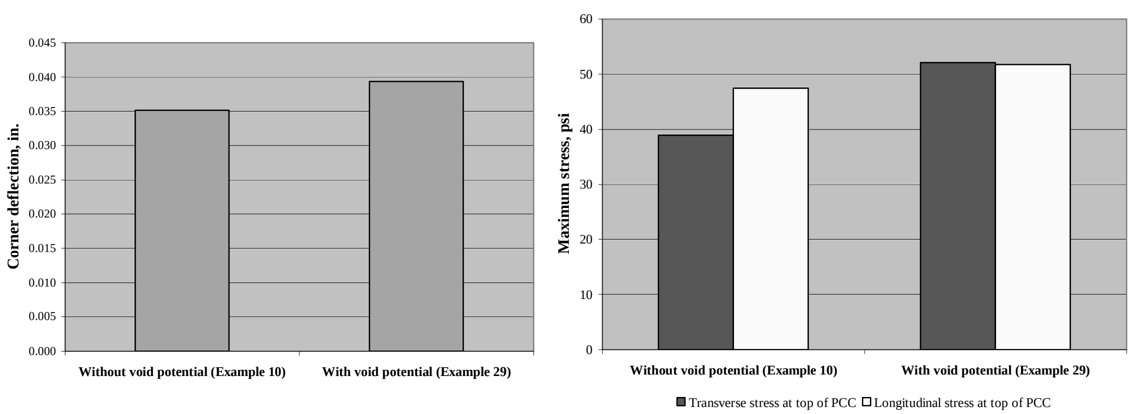


Figure E29-8: Comparison of the Results Between with and Without Void Potential

Example 30:
Three-layer System

Problem Statement

Analyze the pavement system in Example 8, but consider a three-layer system (PCC, DAGB, sand subbase) instead of the two-layer system. Then, compare the analysis results with the results in Example 8.

Given

Sand sub base thickness	=	20	in.

Problem Illustration

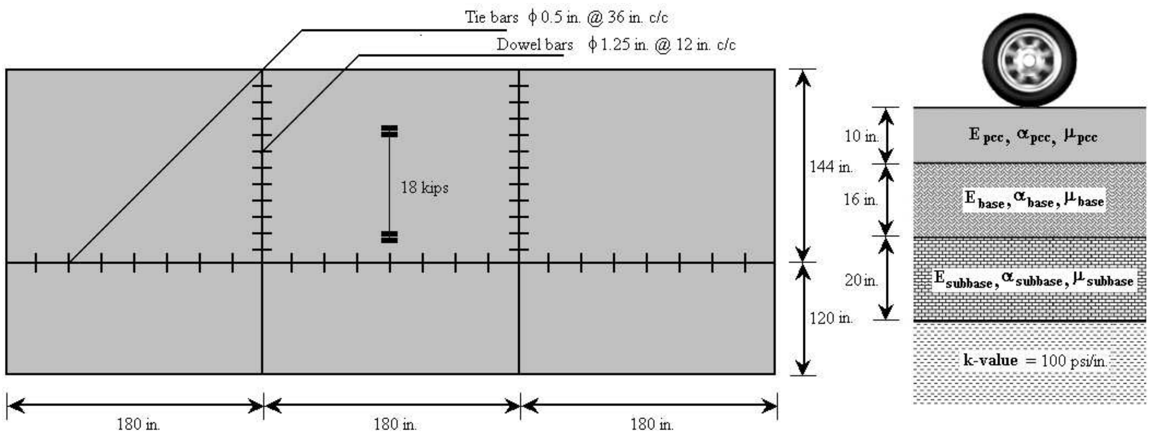


Figure E30-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 8.

Layers Module

(see Figures E30-2)

Step 1: Follow steps 1 through 4 of this module in Example 8.

Step 2: Add a third layer, and then enter the layer properties for sand subbase as illustrated in Figure E30-2.

Step 3: Click **OK** to close the layers panel.

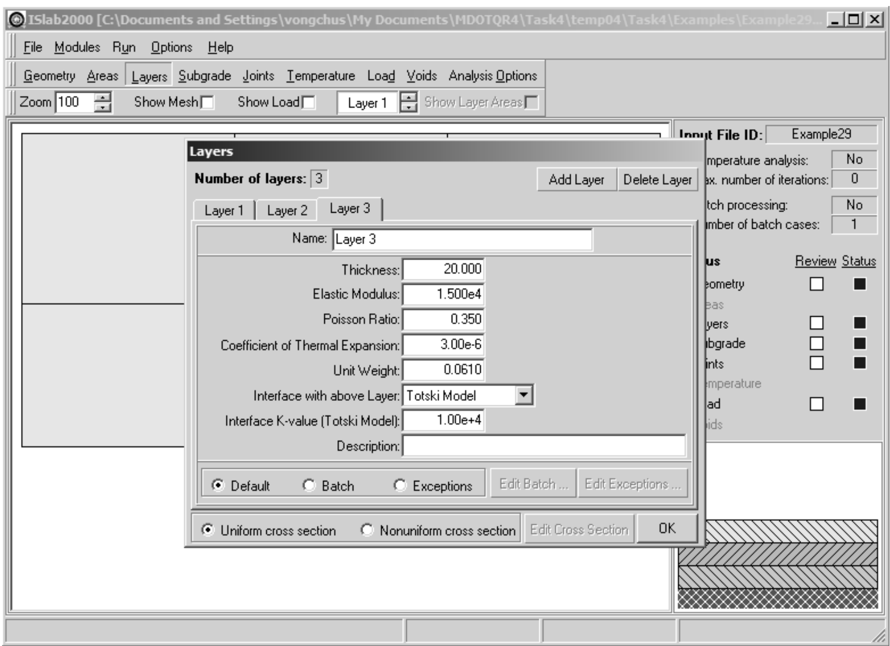


Figure E30-2: Edit Inputs for the Layers Module

Subgrade Module

Use this module from Example 8.

Joints Module

Use this module from Example 8.

Load Module

Use this module from Example 8.

Temperature Module

This module is not required for this problem.

The main panel should display the pavement structure, loading condition, and meshing as shown in Figure E30-3.

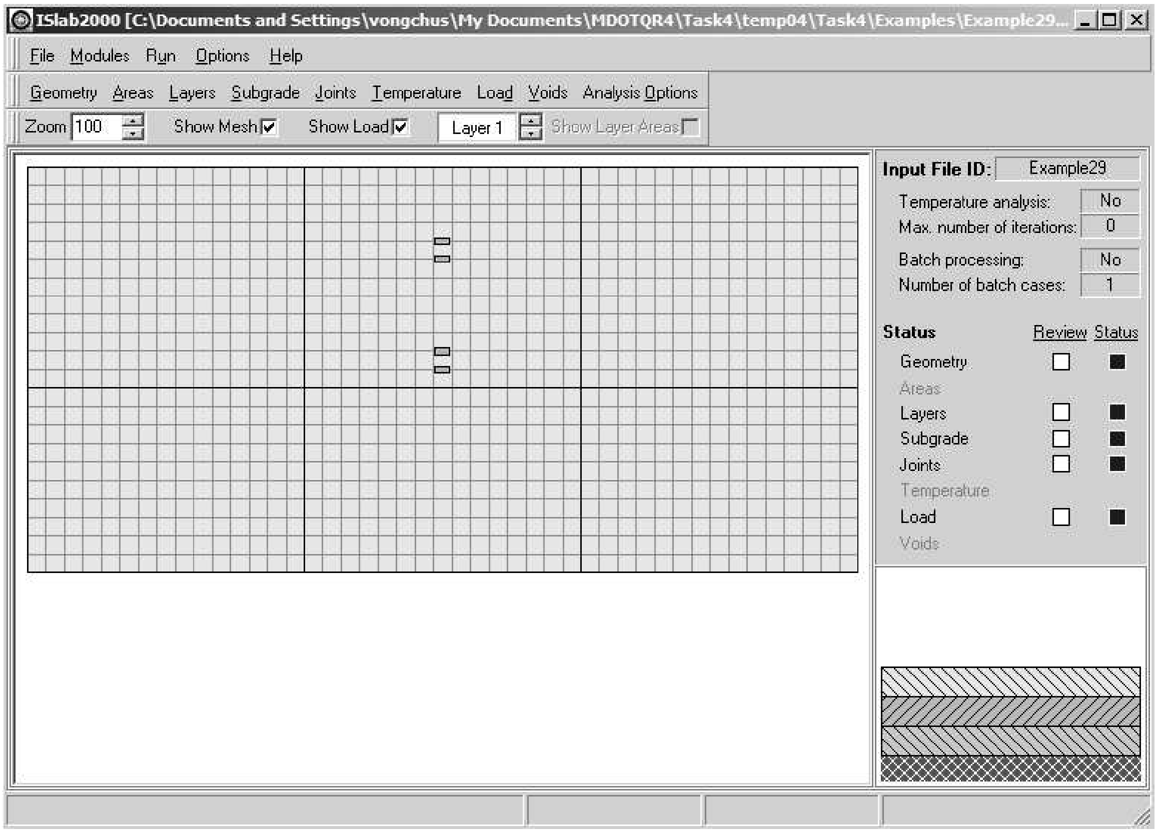


Figure E30-3: Main Panel After Completion of Inputs

Analysis Results

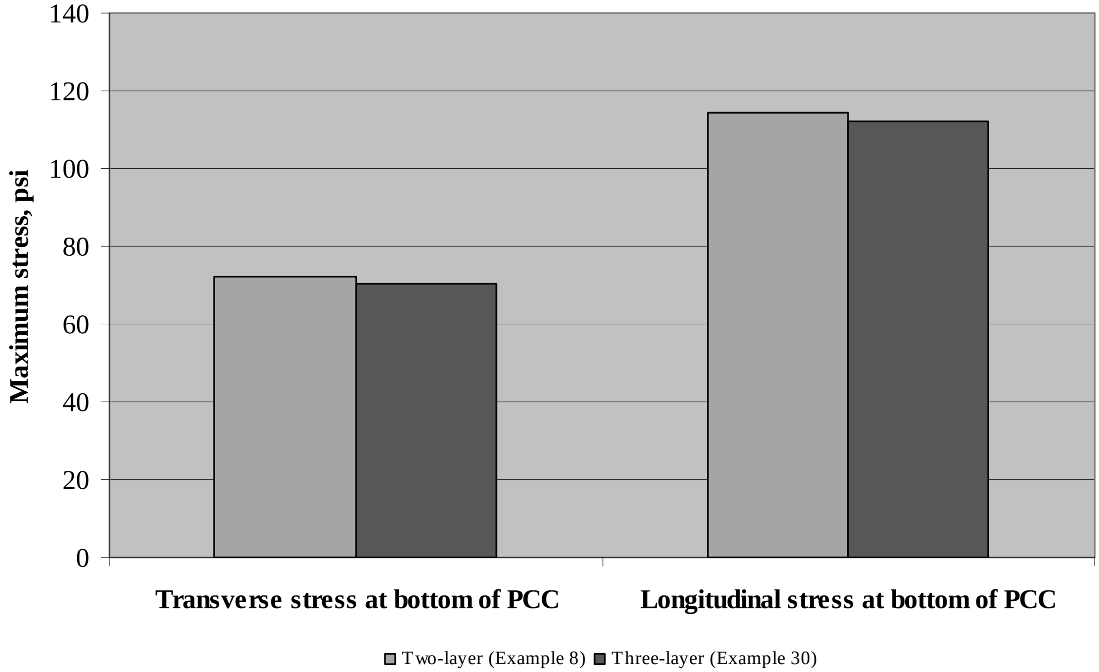
Pavement system	Transverse stress at bottom of PCC	Longitudinal stress at bottom of PCC
Two-layer (Example 8)	72.1	114.5
Three-layer (Example 30)	70.3	112.1

Table E30-1: Analysis Results

NOTE

Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Figure E30-4 illustrates relationship between maximum stresses and pavement system.



E30-4: Relationship Between Stresses and Pavement System

Example 31:
Non-linear Temperature Profiles

Problem Statement

Analyze the pavement system in Example 9, but consider the two non-linear temperature profiles identified in Figure E31-1 instead of a linear temperature differential of +20 °F. Then, compare the analysis results with the results in Example 9.

Problem Illustration

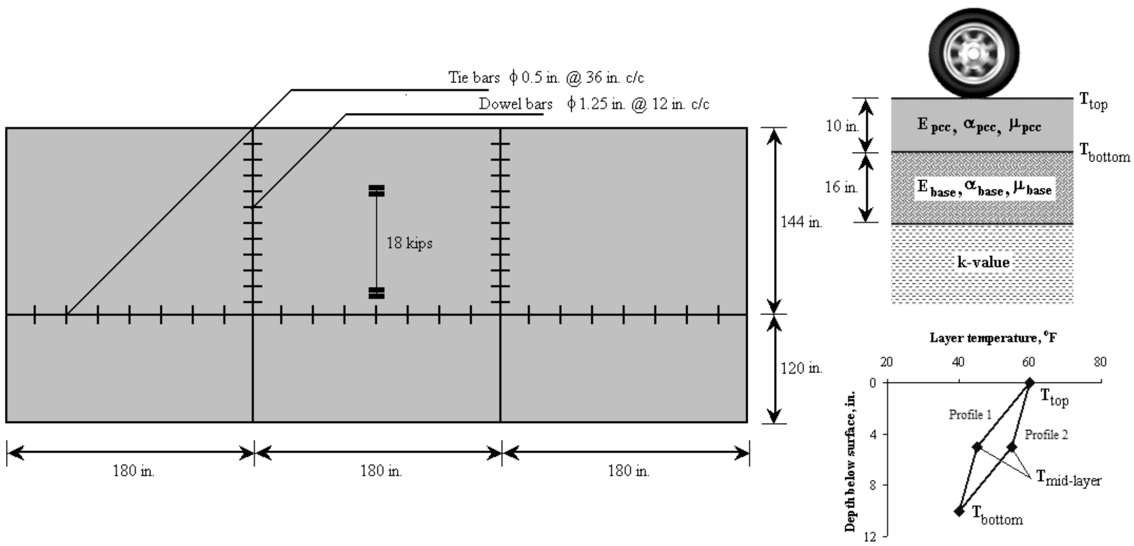


Figure E31-1: Problem Illustration

Solution

Geometry Module

Use this module from Example 8.

Layers Module

Use this module from Example 8.

Subgrade Module

Use this module from Example 8.

Joints Module

Use this module from Example 8.

Load Module

Use this module from Example 8.

Temperature Module

(see Figures E31-2 and E31-3)

Step 1: Click **Temperature** to open the temperature properties panel.

Step 2: Select the **Perform Temperature Analysis** and the **Batch** check boxes.

Step 3: Select **Nonlinear** in the **Type** field for layer 1, select **Batch**, and then click **Edit Batch** to open the layers temperature distributions panel.

Step 4: On Layer 1, enter the identified layer temperatures for the two profiles as shown in Figure E31-2.

Step 5: On Layer 2, enter zero in the other temperature differential across the base layer (see Figure E31-3.)

Step 6: Click **OK** to close the layers temperature distributions panel.

Step 7: Click **OK** to close the layers temperature properties panel.

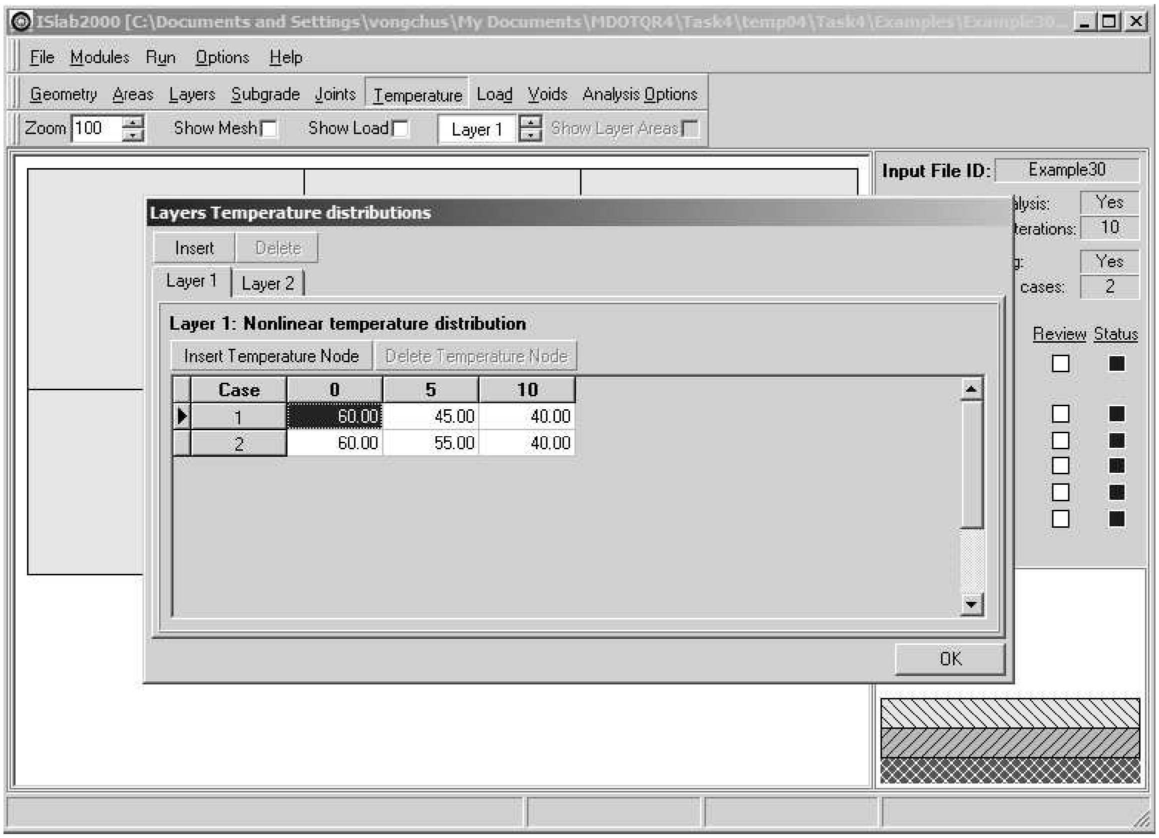


Figure 30-2: Edit Inputs for the Temperature Module

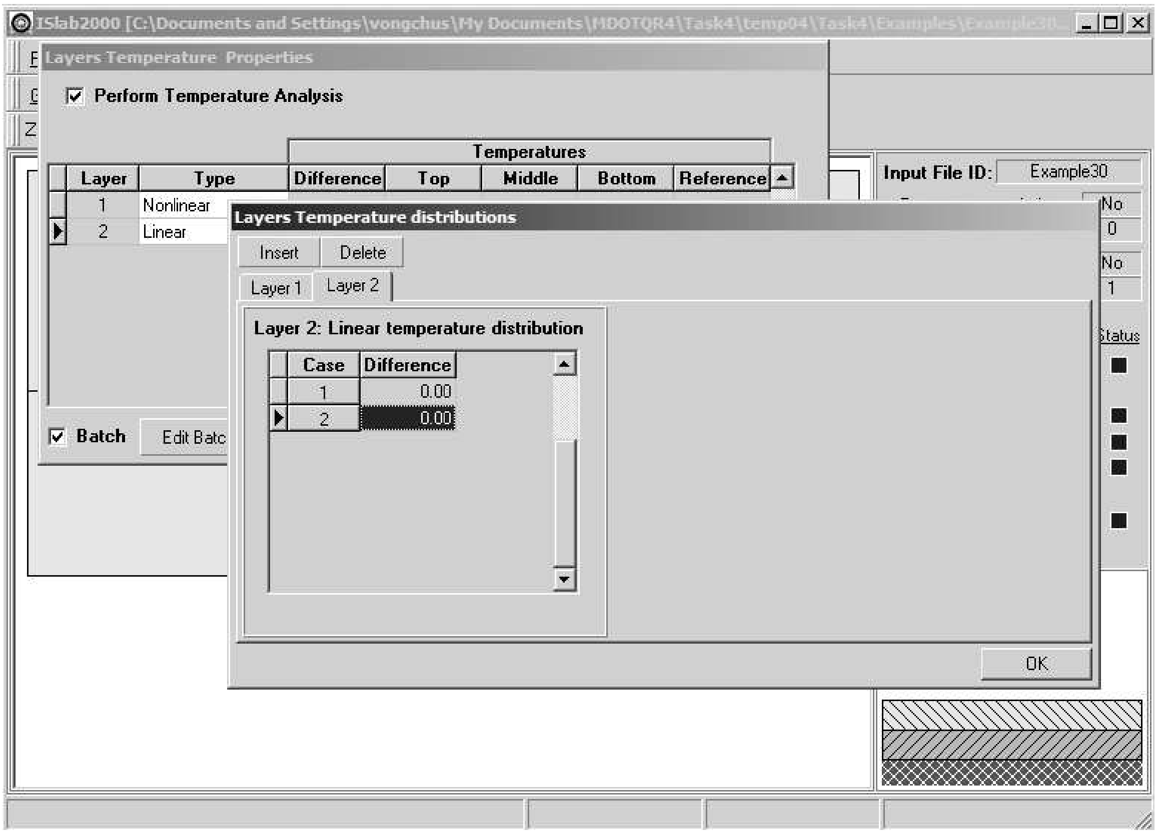


Figure E31-3: Edit Inputs for the Temperature Module (continued)

Analysis Options Module

Use this module from Example 4.

The main panel should display the pavement structure, loading condition, and meshing as shown in Example 8, Figure E8-12.

Analysis Results

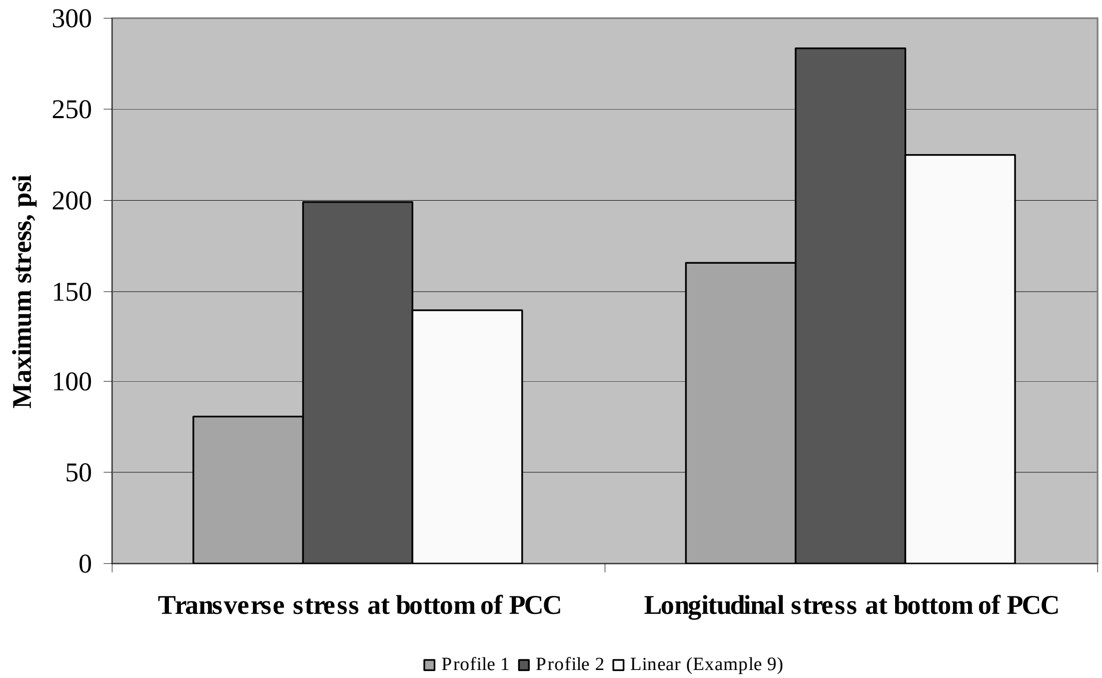
Temperature characteristic	Transverse stress at bottom of PCC	Longitudinal stress at bottom of PCC
Profile 1	80.9	165.4
Profile 2	198.5	283.0
Linear (Example 9)	139.7	224.5

Table E31-1: Analysis Results

NOTE

Positive and negative values of stress signify tensile and compressive stresses and positive value of deflection indicates deflection in downward direction.

Figure E31-4 illustrates relationship between maximum stresses and layer-temperature characteristic.



E31-4: Relationship Between Stresses and Layer-temperature Characteristic

Part III: Practice with Actual MDOT Designs

Problem Statement

Use ISLAB2000 to compute the following:

a) Maximum longitudinal stress at the bottom of the PCC slab under 18-kips single axle edge loading

b) Repeat part a) with a thermal gradient of +4 ^{o}F/in.

c) Maximum longitudinal stress at the top of the PCC slab under 18-kips single axle corner loading

d) Repeat part c) with a thermal gradient of -4 ^{o}F/in.

Design No.	PCC thickness (in.)	Base thickness (in.)	k-value (psi/in.)	Joint spacing (in.)	Outer lane width (in.)	Shoulder width (in.)	Shoulder type	Joint design
1	11.8	15.7	99	315	144	120	PCC	Doweled 1.25 in. diameter at 12 in. center to center
2	11.0	3.9	129	315	144	120	AC	
3	11.0	3.9	129	315	144	120	AC	
4	11.0	3.9	129	315	144	120	AC	
5	11.0	3.9	169	177	168	96	AC	
6	9.4	3.9	158	177	168	96	AC	
7	9.4	3.9	158	177	168	96	AC	
8	9.4	3.9	158	177	168	96	AC	
9	10.2	15.7	221	177	144	-	Valley gutter	
10	11.0	3.9	129	315	144	120	PCC	
11	9.4	3.9	140	315	144	-	Valley gutter	
12	10.2	3.9	158	177	144	120	AC	
13	10.2	3.9	88	315	144	120	PCC	
14	10.2	3.9	151	315	144	144	PCC	

Table P1: Recent MDOT Rigid Pavement Designs

Answer Key

Design No. 1

a) 87.1 psi, b) 557.5 psi, c) 9.7 psi, d) 426.1 psi

Design No. 2-4

a) 115.6 psi, b) 573.5 psi, c) 21.5 psi, d) 383.8 psi

Design No. 5

a) 97.1 psi, b) 291.7 psi, c) 0.9 psi, d) 152.6 psi

Design No. 6-8

a) 119.2 psi, b) 372.3 psi, c) 2.4 psi, d) 191.0 psi

Design No. 9

a) 102.2 psi, b) 378.4 psi, c) 3.8 psi, d) 225.7 psi

Design No. 10

a) 92.0 psi, b) 551.6 psi, c) 13.2 psi, d) 384.9 psi

Design No. 11

a) 122.8 psi, b) 549.1 psi, c) 23.3 psi, d) 389.3 psi

Design No. 12

a) 129.5 psi, b) 349.7 psi, c) 4.7 psi, d) 153.3 psi

Design No. 13

a) 110.5 psi, b) 539.6 psi, c) 14.9 psi, d) 370.7 psi

Design No. 14

a) 98.9 psi, b) 553.0 psi, c) 15.7 psi, d) 394.4 psi